~~Gov. Doc~~
M.

U.S. Mines Bureau of.

Bulletin 200

DEPARTMENT OF THE INTERIOR
ALBERT B. FALL, SECRETARY
BUREAU OF MINES
H. FOSTER BAIN, DIRECTOR

EVAPORATION LOSS OF PETROLEUM IN THE MID-CONTINENT FIELD

BY

J. H. WIGGINS

TN
23
U4
no. 200

ENGINEERING
ENGIN STORAGE

LIBRARY
JUN 18 192
UNIVERSITY OF TORONTO

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

Bulletin 200

DEPARTMENT OF THE INTERIOR
ALBERT B. FALL, Secretary

BUREAU OF MINES
H. FOSTER BAIN, Director

EVAPORATION LOSS OF PETROLEUM IN THE MID-CONTINENT FIELD

BY

J. H. WIGGINS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

The Bureau of Mines in carrying out one of the provisions of its organic act—to disseminate information concerning investigations made—prints a limited free edition of each of its publications.

When this edition is exhausted copies may be obtained at cost price only through the Superintendent of Documents, Government Printing Office, Washington, D. C.

The Superintendent of Documents *is not an official of the Bureau of Mines.* His is an entirely separate office, and he should be addressed:

SUPERINTENDENT OF DOCUMENTS,
Government Printing Office,
Washington, D. C.

The general law under which publications are distributed prohibits the giving of more than one copy of a publication to one person. The price of this publication is 20 cents.

Persons desiring for lecture purposes the use, free of charge, of lantern slides of the illustrations in this publication should make request of the Director of the Bureau of Mines, Washington, D. C.

First edition, February, 1922.

CONTENTS.

Page.
Introduction — 3
Acknowledgments — 4
Part I.—General discussion of evaporation problem and methods of attack — 5
  Consensus of opinion of oil industry — 5
  Various conditions under which evaporation takes place — 5
    Leaks — 6
    Spray — 6
    Ebullition — 6
    Evaporation — 6
  Discussion of gravity and specific gravity — 6
  Problems of saving — 6
  Limitations of the present investigation — 7
  Comparison of oils — 7
  Change in oil and conditions of evaporation as a field grows older — 8
  History of oil from well to refinery — 8
    Lease gathering system — 8
    Receiving or flow tanks — 8
    Dehydration plants — 9
    Lease storage tanks — 10
  Transportation to refinery — 10
    Tank farms and refinery tanks — 10
  Classification and location of losses — 10
    Classification — 10
    Distribution of each class of conditions — 11
  Method of determining losses — 12
    Field work — 12
    Laboratory work — 15
    Formula for determinating evaporation loss — 15
    Distillations — 16
    Plotting of distillation data — 17
    Correction for distillation data — 18
    Three methods of determining evaporation loss from distillations — 19
      1. Specific gravity formula — 19
      2. Temperature—percentage distilled data — 20
      3. Gravity or temperature curves — 20
      Comparison of methods — 21
  Sources of error — 22
    Personal errors — 22
    Errors of method due to temperature increase — 22
      Expansion of steel tanks and measuring tapes — 23
      Thermal expansion factor of oil — 23
  Apparatus used in determining quantity of oil — 24
    Measuring tape — 24
    Hook gage — 24

Part I.—General discussion of evaporation problem and methods of attack—Continued.
  Apparatus used in determining quantity of oil—Continued. Page.
    Tank thermometer 24
    Thieving thermometer 24
    Sampler 26
    Sample cans 26
    Distillation apparatus 26
  Presentation of results 27
    Percentage of original volume lost 27
    Actual volume lost 27
    Actual value lost 27
    Percentage of value lost 28
      Gasoline value v. field price of crude 28
      Gasoline value v. price of refined products 29
      Crude v. crude at any price 29
Part II.—Volumetric loss from evaporation during various stages of handling 30
  Introduction 30
    Nature of tests 30
  Evaporation losses in dehydration by steaming 30
    Conditions for making tests 30
    Description of plant 31
    Method of determining evaporation loss 31
    Temperatures recorded 33
    Making the tests 33
    Scope of tests 34
    Results 35
    General discussion of dehydrator tests 39
      Discussion of errors 39
      Comparison of plant used to general conditions of such plants 40
  Factors causing variation in percentage of loss 40
  Evaporation losses in filling lease storage-tanks 42
    Description of layouts 42
    Results of tests 43
    Conclusions from filling-tank tests 44
  Evaporation losses in storing oil on the lease 44
    Determination of an average tank 44
    Description of types of tanks 45
    Special types of tanks 46
    Average period of storage on the lease 48
    Seasonal temperatures in the Mid-Continent field 48
    Change in rate of evaporation with change of temperature 49
    Method of running a test 51
    Description of tests 51
    Classification 51
    Percentage of volume and actual volume lost 51
      250-barrel unprotected steel tanks—summer, autumn, and winter 55
      500-barrel unprotected steel tanks—different seasons 56
      500-barrel jacketed steel tanks—different seasons 56
      1,600-barrel housed wood tanks—different seasons 57

Part II.—Volumetric loss from evaporation during various stages of handling—Continued.

Evaporation losses in storing oil on the lease—Continued.

Percentage of volume and actual volume lost—Continued.

Page.

Comparison of 250 and 500 barrel unprotected steel and 1,600-barrel housed wooden tanks 58
Comparison of jacketed and unprotected steel tanks 59
Comparison of jacketed and housed tanks 60
Comparison of housed and unprotected steel tanks 61
Loss by so-called empty tanks 62
Actual value and percentage of value lost 62
250-barrel unprotected tanks 63
500-barrel unprotected and 1,600-barrel housed tanks 64
Percentage of value and volume lost on the lease in the Mid-Continent field 64
Condensed data on the three principal types of tanks 67
General discussion of lease-storage experiments 70
Evaporation losses during storage in 37,000 and 55,000 barrel storage tanks 70
Location of tests 70
Evaporative conditions in 55,000-barrel tanks 70
Method of making tests 71
Results of tests 71
Comparison of black and white tanks 74
Check by distillations 74
Miscellaneous data on large tanks 75
Oil temperatures throughout tank 75
Possible accuracy of obtaining oil temperatures 76
Possible accuracy of measuring oil depth 78
Combined error in obtaining volume of oil in tank 78
Volumetric variation of vapor above oil 79
Evaporation losses in transferring oil from lease to refinery by tank car 79
First test 79
Layout 79
Results 80
Second test 80
Layout 80
Field work 81
Results from distillations 82
Discussion of results 83
Evaporation losses in filling a 10,000-barrel steel tank 84
Method of test 84
Results 84
General discussion of all results 85
Apportionment of loss—well to refinery 85
Decrease of evaporation loss 86
Value of protecting tanks 87
Conclusions 87
Additional work on evaporation 87
Part III.—Scientific data on the evaporation of petroleum products 89
Vapor pressure 89
Latent heat of evaporation 90

Part III.—Scientific data on the evaporation of petroleum products—Continued.

Page.

Convection currents in oil 91
Viscosity 91
Conditions to be attained to decrease evaporation 91
Changes in oil and in the part lost by evaporation 92
Source of data 92
Effect on gravity of crude 92
Gravity of fraction evaporating 94
Boiling point of fraction evaporating 95
Gravity of portion evaporated 95
Laboratory evaporation tests 95
Comparison of rates of evaporation of petroleum and pure gasoline from the same petroleum 95
Evaporation of gasoline exposed in the pure state and after blending with heavy lubricating oil 98
Relation of the gravity of gasoline to the rate of evaporation of the original crude 99
Effect of blending light gasoline with heavier products 100
Rate of evaporation of gasolines derived from crudes from diferent sources 101
Conclusions from laboratory tests 103
Rate of evaporation of crudes from different sources 103
Comparison of Mid-Continent oils by distillations 105
Proportion of gas dissolved in oil 106
General conclusions 107
List of publications on oil-field technology 109
Index 111

TABLES.

Page.

Table 1. Form of keeping field notes and making calculations to obtain evaporation loss at the lease storage tank 14
2. Form for keeping distillation records on evaporation work 16
3. Form for determining evaporation loss by formula 20
4. Typical results of four methods of determining per cent of loss due to evaporation 22
5. Field data taken on dehydrator test June 20, 1919 35
6. Summarized results of dehydrator evaporation tests 36
7. Evaporation loss in dehydration plants of different daily capacities and for different temperatures 42
8. Conditions and results of tests on filling lease tanks 43
9. Size of tanks from which the three principal groups are determined 45
10. Number of days that oil is held on the lease throughout the year 48
11. Scope of lease-storage experiments covering 40 field tests 51
12. Classification for comparing percentage of volume and actual volume lost 53
13. Classification for comparing actual and percentage of value lost 63

Page.
TABLE 14. Loss in the Mid-Continent field by five days' storage on the lease, 1919 65
15. Percentage of volume, actual volume in barrels, and value in dollars lost as crude in various types of lease storage 68
16. Classification of 55,000-barrel tanks 72
17. Temperature comparisons in 55,000-barrel tanks with thieving thermometers, showing possible accuracy 77
18. Readings showing possible accuracy of gaging a 55,000-barrel tank 78
19. Volume of air above oil in a 55,000-barrel tank and its thermal expansion for various conditions 79
20. Results of first test—lease to refinery 80
21. Results of second test showing percentage of volume lost by evaporation during movement of oil from well to refinery 83
22. Results of test—filling a 10,000-barrel tank, Aug. 21, 1919 85
23. Apportionment of the loss sustained by crude from well to refinery 85
24. Average time of storage of crude by pipe-line companies, Mid-Continent field 86
25. Saving attained by protection of tanks by housing or jacketing 87
26. Vapor pressure, in millimeters of mercury, of gasoline of different gravities and percentage of gasoline vapor for saturating air at different temperatures 89
27. Results of tests to determine the comparative rates of evaporation of gasoline in the pure state and as it exists naturally in the crude 98
28. Results of tests comparing the rate of evaporation of gasoline exposed in pure state and when blended with lubricating oil 99
29. Results of tests to determine the amount of gas in oil that is noncoverable by ordinary condensation 107

ILLUSTRATIONS.

Page.
PLATE I. *A*, Flow tank to separate gas from oil; *B*, First stage of dehydration 32
II. *A*, Tanks used for measuring the volume entering dehydration plant during test; *B*, Loading tank cars 33
III. *A*, Dehydrator as used before test; *B*, Measuring-tank scaffold erected for dehydration test; *C*, Plant equipped for test 34
IV. *A*, First stage of dehydration, oil entering at top; *B*, Oil entering second stage of dehydration 35
V. *A*, Housing for wooden lease-tanks; *B*, Battery of 500-barrel unprotected steel tanks; *C*, Typical condition of the roofs of such tanks as are shown in Plate V, *B* 46
VI. *A*, Overshot connection for large lease-tank; *B*, Large steel tanks with bad roof, showing carelessness regarding evaporation losses 47
VII. *A*, Top of jacketed tank before construction of roof; *B*, Roof of jacketed tank, showing door open; *C*, Battery of jacketed steel lease-tanks 48

Page.

FIGURE 1. Course of oil from well to refinery 9
2. Curves plotted from distillation data of samples taken from same tank of oil on two different dates, the first before evaporation and the latter after an evaporation loss of 8 per cent 17
3. Details of thieving thermometer used to obtain accurate temperature readings at any depth of a tank of oil 25
4. Plant equipped for dehydration by passing emulsion through hot water 31
5. Dehydrator tank showing closed steam coils 32
6. Temperature conditions of third dehydrator test 34
7. Effect of temperature of dehydrators on volume lost 36
8. Variation of actual value lost with increasing temperature of dehydrators 37
9. Effect of temperature of dehydrators on loss of gravity of oil 38
10. Cumulative percentage of volume lost as the oil passes through successive stages of the dehydration plant 38
11. Three dehydration plants handling the same daily production under different conditions 41
12. Layout for determining evaporation loss in filling lease tank 42
13. Test 2, temperature conditions and results of test of filling lease tank 44
14. Wood housing for 1,600-barrel lease stock-tank to decrease the circulation of air 46
15. Practically airtight jacket around steel lease-tank 47
16. Method of obtaining average normal temperatures for the four seasons of the year in the Mid-Continent field 49
17. Variations of percentage of volume lost from 250-barrel unprotected steel tanks with variation of mean oil temperature 50
18. Variation of percentage of volume lost from 500-barrel unprotected steel tanks and 1,600-barrel housed wood tanks with variation of mean oil temperature 50
19. Mean oil temperatures at which lease-storage tests were run for summer, autumn, and winter 54
20. Comparison *A*. Barrels evaporated and percentage of volume evaporated from 250-barrel unprotected steel lease-tanks during the summer, autumn, and winter 54
21. Comparison *B*. Barrels evaporated and percentage of volume evaporated from 500-barrel unprotected steel lease-tanks during the summer, autumn, and winter 55
22. Comparison *C*. Barrels evaporated and percentage of volume evaporated from 500-barrel jacketed steel tanks during summer, autumn, and winter, and respective mean temperatures of oil 56
23. Comparison *D*. Barrels evaporated and percentage of volume evaporated from 1,600-barrel housed wood tanks during summer, autumn, and winter 57
24. Comparison *E*. Barrels evaporated and percentage of volume evaporated from 250 and 500 barrel unprotected steel tanks and 1,600-barrel housed wood tanks in summer 58
25. Comparison *F*. Comparison of barrels evaporated and percentage of volume evaporated from 500-barrel unprotected and jacketed steel tanks in autumn 59

Page.

FIGURE 26. Comparison *G*. Comparison of barrels evaporated and percentage of volume evaporated from 500-barrel unprotected and jacketed steel tanks in winter 60

27. Comparison *H*. Comparison of barrels evaporated and percentage of volume evaporated from 1,600-barrel wood tanks and 500-barrel jacketed steel tanks in autumn 61

28. Comparison *I*. Comparison of barrels evaporated and percentage of volume evaporated from 250-barrel housed steel tanks and from 250-barrel unprotected steel tanks during summer 62

29. Comparison *J*. Actual value lost by 250-barrel unprotected steel tanks for the average season 63

30. Comparison *K*. Actual value of loss from 500-barrel unprotected steel tanks for the average season 64

31. Comparison *L*. Actual value of loss from 1,600-barrel housed wood tanks 65

32. Percentage of value lost by average tank (750 barrels) for the average season. Percentage of volume lost by similar tank by seasons for any period of storage to 40 days on the Mid-Continent field 66

33. Average conditions during storage in large steel tanks 70

34. Comparison of the rates of evaporation of oils of different ages. First test 72

35. Comparison of rates of the evaporation of oils of different ages stored in 55,000-barrel tanks. Second test 73

36. Results of test made on 1,440,235 barrels stored in standard steel 55,000-barrel tanks, showing loss from evaporation 73

37. Comparison of volume evaporated from black and from white 55,000-barrel tanks 74

38. Composite results of distillations of oil of different ages in 55,000-barrel tanks, showing the effect of evaporation 75

39. Variation of oil temperatures from the bottom to the oil surface in a 55,000-barrel tank for summer and autumn. Corresponding temperature of mixture of vapor and air above oil 76

40. Oil and vapor temperatures throughout the day for 55,000-barrel steel tank, Aug. 11, 1919 77

41. Layout for determining evaporation loss in handling oil from lease to refinery by tank car. Second test 81

42. Effect of evaporation as shown by distillation curves on second "lease-to-refinery" test 82

43. Percentage of volume lost by oil through evaporation, by stages, from well to refinery. Second test 83

44. Variation of percentage of gasoline vapor necessary for saturation of air at different temperatures, as °B. of gasoline varies 90

45. Drop in °B. gravity of crude stored in different kinds of tanks—summer 93

46. Degrees, Baumé, gravity of fraction evaporating for tanks of various kinds—summer 93

47. Boiling points of fractions evaporating from tanks of various kinds—summer 94

Page.

FIGURE 48. Degrees, Baumé, gravity of the portion that has evaporated from tanks of various kinds—summer ---- 94
49. Comparison of evaporation of El Dorado, Kans., crude and the gasoline and kerosene cuts from that crude exposed in pure state ---- 96
50. Comparison of evaporation of crude from Ranger field, Texas, and the gasoline and kerosene cuts from that crude exposed in pure state ---- 96
51. Comparison of evaporation of crude from Coalinga field, California, and the gasoline and kerosene cuts from that crude exposed in pure state ---- 97
52. Comparison of evaporation of crude from Coalinga field, California, and the gasoline and kerosene cuts from that crude exposed in pure state ---- 97
53. Comparison of evaporation of pure gasoline and the same gasoline when blended with heavy lubricating oil in the ratio of 1 to 9 ---- 98
54. Relation between the °B. of gasoline in a crude oil and the ratio of the rates of evaporation of (1) crude oil and the first 10 per cent of gasoline distilled therefrom; (2) gasoline and a blend of the same gasoline with heavy lubricating oil ---- 100
55. Comparison of evaporation of 61° B. gasoline and the same gasoline blended with heavier cuts ---- 100
56. A comparison of evaporation of gasoline of 66.9° B. to that of a blend of it with mineral seal oil ---- 101
57. Comparison of evaporation of gasolines from Ranger, Tex., and Coalinga, Calif., light crudes ---- 102
58. Comparison of evaporation of gasolines from Ranger, Tex., and El Dorado, Kans., crudes ---- 102
59. Relative rates of evaporation of gasolines from different fields ---- 103
60. Comparison of the rates of evaporation of El Dorado, Kans., Ranger, Tex., and Coalinga, Calif., crudes, with distillation curves for each ---- 104
61. Comparison of crude oils from El Dorado, Kans., Garber, Okla., and Ranger, Tex., by distillations ---- 106

EVAPORATION OF PETROLEUM IN THE MID-CONTINENT FIELD.

By J. H. Wiggins.

INTRODUCTION.

In 1919 the United States was threatened with a shortage of gasoline. In spite of this well-known fact, a detailed field investigation has shown that in one stage only of handling crude oil the volume of gasoline that evaporates is equal to one-thirtieth of the country's yearly gasoline production. This loss occurs during the few days that the oil is stored on the leases before being taken by the pipe line, and in 1919, in the Mid-Continent field alone, it amounted to 122,100,000 gallons. Large as it is, it is only a part of the loss on the lease.

Investigation has further shown that the gasoline in crude oil evaporates from one-half to six-tenths as rapidly as the same gasoline after being distilled and stored, all evaporative conditions being the same.

Many wastes in the oil fields are called "necessary." By this is meant that the cost of preventing the waste is greater than the gain through saving. Evaporation losses have fallen heretofore in this category, but now they must be considered unnecessary. In other words, it is no longer economical for any handler of crude oil to permit losses through evaporation.

In accordance with its purpose of seeking to conserve mineral resources, the Bureau of Mines investigated the loss of gasoline by evaporation in the storage and handling of petroleum. Inasmuch as most producers had not decided that their losses justified corrective measures and no evidence was available on the comparative losses in various stages of handling the oil, the investigation was limited to determining by experiment and observation the nature and magnitude of evaporation losses, where the greatest losses are, and the factor controlling evaporation.

The results of the investigation, as presented in this report, indicate that losses from evaporation are so large that they should receive serious consideration at once by the industry, which should make every endeavor to reduce them to a minimum. The Bureau of Mines is now making a supplementary study of methods of reducing these losses.

This bulletin has three parts: First, a general discussion of the problem and the methods of attack; second, volumetric losses during various stages of handling and in various kinds of storage; third, scientific data on the evaporation of petroleum.

ACKNOWLEDGMENTS.

The preparation of this report was made possible by the active aid of certain oil companies in the Mid-Continent field, including the Prairie Oil & Gas Co., the Empire Gas & Fuel Co., the Magnolia Petroleum Co., the Sinclair Oil & Gas Co., and the Marland Refining Co. Others offered assistance, but owing to lack of time, it was impossible to take advantage of their courtesy.

Especial thanks for interest shown in this work are due Mr. Herbert Straight, general manager; Mr. H. O. Ballard, former superintendent of production; and Mr. R. M. Stuntz, superintendent of production, of the Empire Gas & Fuel Co.; Mr. E. R. Brown, vice president and general manager of the Magnolia Petroleum Co.; Mr. N. K. Moody, vice president of the Prairie Oil & Gas Co.; and Mr. C. R. Waltz, in charge of the Prairie Oil & Gas Co. tank farms at Ranger, Tex. Much help was given by department heads of these oil companies and their assistants.

The engineers who aided in the field work are D. S. Foster, J. H. Simmons, and J. P. Murray, of the Empire Gas & Fuel Co., and A. L. Gersdorff, of the Magnolia Petroleum Co.

C. P. Bowie, in charge of the San Francisco office of the Bureau of Mines, has given encouragement and constructive criticism. J. O. Lewis, former chief petroleum technologist of the bureau, has shown continued interest in this work.

While determining methods of making distillations the author consulted E. W. Dean, of the Pittsburgh station, and R. O. Neal, of the Bartlesville station, of the bureau. S. M. Law of the Bartlesville station made nine-tenths of the distillations; L. A. Penn and E. C. Lane, of the San Francisco office, made the rest. All curves and sketches were drawn by J. G. Shumate, of the San Francisco office.

A. R. Elliott, H. H. Hill, E. W. Dean and A. W. Ambrose, of the Bureau of Mines, offered helpful criticisms.

Mr. W. E. Perdew, of the Union Petroleum Co., made valuable suggestions and additions.

PART I.—GENERAL DISCUSSION OF EVAPORATION PROBLEM AND METHODS OF ATTACK.

CONSENSUS OF OPINION OF OIL INDUSTRY.

This investigation was authorized because of the general knowledge that in handling or storing crude oil an appreciable loss from evaporation occurred. More than 40 men, representing the petroleum industry in all its departments, and including engineers, superintendents, managers, and vice presidents of producing, pipe-line, and refining companies and companies which manufacture gasoline from natural gas, were interviewed to determine what they had done toward the elimination of evaporation losses and what their attitude had been regarding such losses. The consensus of their opinions was as follows:

The proportion of the lighter products that evaporate from crude oil from the time it leaves the well until it reaches the refinery was not known even approximately. All admitted loss and some considered it serious, but more looked upon it simply as a necessary evil, the escape of a valuable product.

The expression was often heard that the oil "settles" or "gas gets out of it." Varying opinions were offered as to the reason for the shrinkage, but the general, vague conclusion of all was that "something happens to it." That evaporation was generally conceded to be an appreciable loss, however, is proved by the fact that a pipe-line company never gages a tank of oil that it is buying unless the oil can be handled immediately.

Some of the larger companies had endeavored to determine their evaporation losses at various stages, but these records had generally been discarded. This did not, however, apply to the handling of refined products, for much had been done to overcome the evaporation of gasoline. Although the companies separately evaded the issue of estimating their own evaporation losses, they were anxious to cooperate with the Bureau of Mines in evolving a standard method of determining and avoiding such losses.

VARIOUS CONDITIONS UNDER WHICH EVAPORATION TAKES PLACE.

It is incorrect to list all evaporation of oil in the field under the general heading "evaporation," as used in the text. Losses that are or are not chargeable to this heading are as follows:

LEAKS.

Connections or tanks may leak so slightly that all of the leakage will evaporate except a black residue commonly seen as a stain on oil-field tanks. It is obvious that such losses are not considered as evaporation but as leaks. They are, therefore, not within the province of this paper.

SPRAY.

When oil flows into a tank from above, the wind may whip some of it away. Such loss is not considered "evaporation," though it is needless and frequently very large. If, however, the oil flows into the tank and then, owing to the splash and spray, vaporizes and is carried off, the loss is charged to "evaporation."

EBULLITION.

Oil forced into the bottom of a tank contains gas and perhaps air, which rise rapidly and form bubbles that burst at the surface. In consequence, finely divided particles of oil are projected into the mixture of air and vapor above the oil. These particles may evaporate very rapidly and be carried off as vapor, or they may be so light that with a slight wind and a nearly full tank they are removed in the liquid state. All such losses are placed under evaporation.

EVAPORATION.

From the above three descriptions, it is quite clear what part of the losses are charged to this item. In this bulletin, "evaporation" refers to the part of the oil lost (under ordinary conditions of handling and storage) after that part has been changed from a liquid to a vapor. This change may occur from a still oil surface, while oil is splashing into a tank, or while the surface is stirred by oil entering a tank at the bottom.

DISCUSSION OF GRAVITY AND SPECIFIC GRAVITY.

In the present report, "gravity" is usually discussed in terms of the familiar Baumé scale, the Bureau of Standards scale with a modulus of 140 being employed. Specific gravity is used when needed, as, for example, in mathematical formulas. The Fahrenheit temperature is that chosen for presenting results.

PROBLEMS OF SAVING.

It is certain that there are no engineering obstacles to the elimination of these losses. The problems involved have been solved in great measure by the natural-gas gasoline industry. Even the so-called "wild" gas could be saved if saving would pay. In some parts of Pennsylvania old gas wells that yield gas of exceptionally high heating value are pumped; the gas which corresponds to the so-called "wild" gas is compressed into cylinders and sold for use in welding. This is possibly an extreme example of saving small losses.

Questions of profit confront the average engineer, however. Does it pay to save vapors? Does the loss of usable vapor justify the expenditure of a fairly large sum, say $5,000, to make the installation that would prevent it? Under some special conditions these questions are answered in the affirmative, but even where they are, the loss is not generally recognized or the means of elimination put into practice. Work has been done to protect tanks from heat by water-sealed tops, lagging, and sprinkling the roofs, but statistics showing the actual value of such protection have not been generally available. In fact, the meager data that have been published do no more than indicate that the evaporation problem should have been considered years ago.

LIMITATIONS OF THE PRESENT INVESTIGATION.

To cover all conditions, an extensive investigation would be necessary, because of the number of the conditions that affect the rate of evaporation of oil. This paper considers merely the handling and storage of the average oil produced in the Mid-Continent field. Naturally, such information will give a standard for estimating the evaporation losses of special oils.

COMPARISON OF OILS.

Crude oils in the field are generally compared by their Baumé gravity, which is, in a rough way, an indication of their gasoline content. For instance, a Garber crude of 45° B. yields about 50 per cent gasoline, whereas an El Dorado 34° B. oil yields about 22 per cent. Although gravity is not the most trustworthy method of determining the comparative values of crudes, it is the most practical field test and is an approximation of the real value and nature of an oil, especially if the field from which the oil comes is known. A distillation test gives the information necessary to judge the relative rates of evaporation of different oils. Such information also shows the quality of the portion lost. An oil of 35° B. evaporates more rapidly than an oil of 40° B. only if the former contains fractions more volatile than those in the latter.

CHANGE IN OIL AND CONDITIONS OF EVAPORATION AS A FIELD GROWS OLDER.

When the first wells are drilled in a new field, much permanent gas is generally found with the oil, sometimes having such a pressure that it forces out the liquid, causing the well to flow intermittently or even steadily. Oil produced under such conditions evaporates very rapidly during the first day or two that it is stored, because it contains much dissolved gas. This gas volatilizes quickly on exposure to the air and naturally carries with it some of the lighter gasoline fractions.

As a field grows older, the gas pressure decreases until the oil has to be pumped. As the oil then has much less permanent gas in solution it evaporates more slowly and, if the conditions of handling are unchanged, does not show the large evaporation losses of the early life of the field.

However, in a new field, when the production is greatest, the oil is handled more quickly; that is, in order to make room for the large production a tank is filled more rapidly and stands full on the lease a shorter period. As production declines, the stream is smaller and the time of filling a tank three or four times as long, or more. An excess of tankage is available for storage, hence the oil is not moved off so soon. Under the same evaporative conditions, therefore, the proportion lost will be largest during the early life of a field. At a later date, however, conditions favoring evaporation may be so aggravated that the percentage of the original volume lost will yet be high.

HISTORY OF OIL FROM WELL TO REFINERY.

Oil passes through pipe lines, pumps, tanks, and railroad tank cars on its way from the well to the refinery. Figure 1 illustrates this oil path and history with the province of each type of company indicated by arrows. A more detailed description of the various steps follows.

LEASE GATHERING SYSTEM.

The lease gathering system is generally 2 or 3 inch pipe connecting the wells either to the lease stock-tank or to the receiving tank. A separate line may run each well to the tank or a number of wells may be joined to a single lead line. Although the oil is mixed with gas, it is under pressure and there is no opportunity for evaporation while in the pipe.

RECEIVING OR FLOW TANKS.

Oil coming directly from the well often contains much gas or free water mixed with it. To separate these, the mixture is run into a “flow tank,” “settling tank,” or “receiving tank” as it is variously called. In the Mid-Continent field, it is customary to separate the oil either from water or from gas, or both, hence two types of flow tank are used. That used to separate the gas has a cover nearly gas-tight, fitted with a short stack to emit the gas. Such a tank is shown in Plate I, *A* (page 32). The tank for separating the free water is of wood or steel, either with no cover or with a very poor one; it is not housed nor protected. Such tanks also separate sand or sediments from the crude oil.

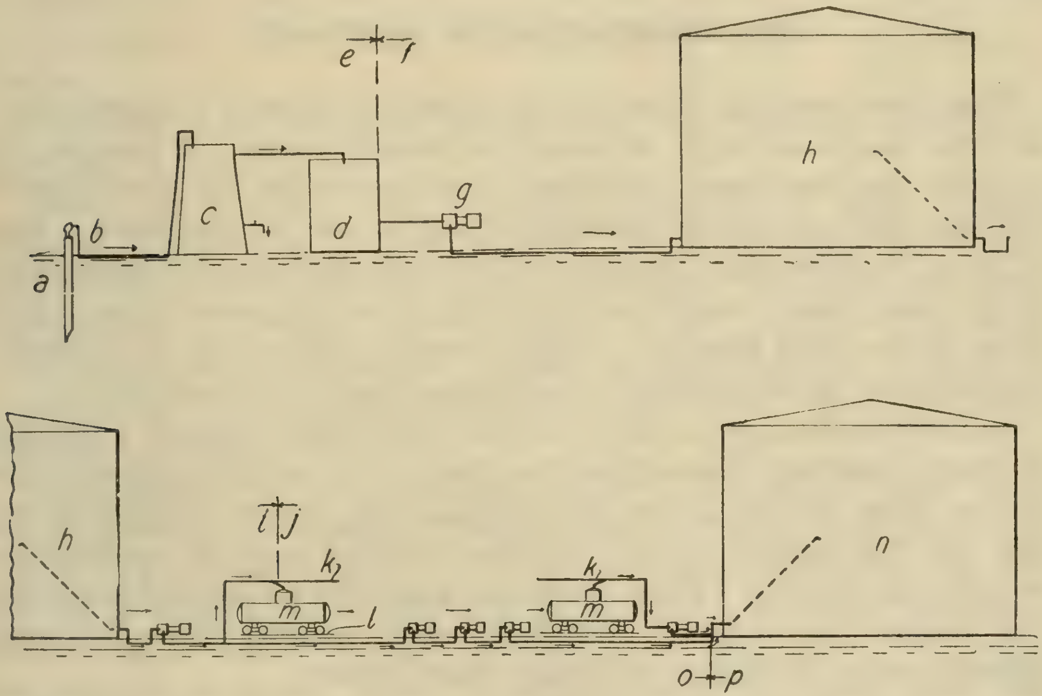


FIGURE 1.—Course of oil from well to refinery: *a*, well; *b*, lead lines; *c*, flow tank; *d*, lease storage-tank; *e*, producing company; *f*, pipe-line company (to *i* or *o*); *g*, pump station; *h*, pipe line to tanks; *i*, pipe-line company; *j*, refining company; *k*, loading rack; *l*, railroad; *m*, tank car; *n*, storage at refinery; *o*, pipe-line company; *p*, refining company.

DEHYDRATION PLANTS.

When water to the extent of 2 per cent or more is emulsified in oil, some special means has to be used for breaking the emulsion so that the water will free itself by gravity. These means include electricity, centrifuge, chemicals, and heat. All of them necessarily involve some evaporation loss of the oil. With the first three methods this is comparatively small, but with the last it is usually very large. In the Mid-Continent field the practice has been to run the oil through hot water ranging in temperature from 100° F. to 200° F. A more detailed description of such plants will be found on page 31. See Plate I, *B*, page 32.

LEASE STORAGE-TANKS.

After having gone through either a flow tank, or both a flow tank and a dehydration plant, the oil flows into storage tanks on the lease—called in this report lease stock or lease-storage tanks—where it is held on an average of about five days before it can be taken by the pipe line. A detailed description of the different types and sizes of these tanks will be found on page 45. Except for losses in dehydration by heating it is in field storage that the losses are greatest.

TRANSPORTATION TO REFINERY.

Pipe lines ranging from 2 to 6 inches or more in diameter connect the lease tank with the pipe-line storage tanks. While the oil is in the pipe line there is no chance for evaporation, but when forced into the tank and stirred violently it suffers loss by ebullition. The oil goes from the pipe line to a type of tank that is better than those on the lease, being usually of steel with a roof supposedly gas tight. After it has stood here for variable lengths of time, the oil is transported to the refinery either by large pipe lines or by tank cars.

In passing through a main pipe line, the oil goes through a number of pump stations. Sometimes the pump at a certain station picks up the oil as rapidly as the pump at the rear station delivers it, but this does not always happen, and there must be tanks at each station to store the surplus. These tanks are generally of 55,000-barrel size and number two or more. Evidently oil in passing through a long pipe line may be flushed into tanks many times.

TANK FARMS AND REFINERY TANKS.

Instead of going directly to the refinery, the oil sometimes stands in storage on tank farms in large steel tanks of 35,000 to 55,000 barrels capacity, with approximately gas-tight roofs. These farms may contain as many as 100 or more such tanks, and some oil may stand there for years. Many refinery crude-oil tanks are like the tanks on the farms and store enough to run the plant a month or more. While the oil is standing in these tanks the rate of evaporation is slower, but the oil is held there for a longer period than on the lease, thus constituting another important point of evaporation loss.

CLASSIFICATION AND LOCATION OF LOSSES.

CLASSIFICATION.

Evaporation losses may be divided, as to rate, among the following five classes of conditions:

1. Filling a tank by overshot connections. This represents the highest loss per unit of time and is an example of loss through spray.
2. Filling a tank by bottom connections, the oil entering at the bottom of the tank and not being exposed to the air except at the surface. This class has a somewhat slower rate of evaporation and represents loss aggravated by ebullition.
3. Storage of oil in small tanks, not protected from the sun's rays nor from the free circulation of air.
4. Storage of oil in small tanks, protected both from the sun and free air circulation.
5. Storage of oil in large 37,500 or 55,000 barrel standard steel tanks.

The last three represent losses from still surfaces or surfaces agitated by wind only.

These five classes of conditions are placed in the order of their rate of evaporation per unit of time, the first having the highest and the last the lowest rate. For example, the oil might lose 1 to 2 per cent of its volume in a few hours while a tank is being filled from an overshot connection. In the last class the rate of evaporation is found to be between 1½ and 3 per cent a year, depending upon the age and kind of oil.

It is necessary to note that the order of this classification holds only for oil of practically the same volatility. For example, an oil which had already evaporated 10 per cent would probably lose less during a transfer from one tank to another, even when a tank is filled from above by overshot connections or from below with possible loss by ebullition, than the original fresh oil would have lost while standing 24 hours in a small tank exposed to sun and air. It is seen, then, that the volatility of the oil affects the rate of evaporation.

Other factors that affect the rate of evaporation are wind velocity, atmospheric temperature, and cloudy or clear weather. Within ordinary limits, however, the method of handling has more effect on evaporation than any other single condition.

DISTRIBUTION OF EACH CLASS OF CONDITIONS.

The loss on the lease is chiefly within the first three classes named. A great deal of oil is splashed and sprayed in filling the flow tank through the usual overshot connection. In addition, the surface of the oil in the flow tank is exposed to the free circulation of air. If the crude is dehydrated by heating, it is again splashed one or two times and its surface again exposed to the air.

In filling the lease tank, loss is caused either by overshot connections or by ebullition. It can usually be accredited to overshot connections, however, because this condition exists at practically all lease tanks. During storage on the lease, after free water, emulsified water, or excessive gas has been separated from the oil, evaporation may take place by storage in unprotected small tanks. Sometimes, however, evaporation is noted from protected small tanks, especially those of wood.

Oil gathered from a number of leases by the pipe-line company and stored in very large tanks is again subjected to an evaporation loss from ebullition, for practically all of the filling connections are at the bottom of the tanks. When a lease tank is emptied, air is often sucked into the gathering system, increasing the effect of ebullition at this point. While oil stands in a pipe-line stock tank, in tank farms, or in refinery-storage farms, it is liable to surface evaporation. Every time that the oil is pumped from one station to another and allowed to flow into a working tank, it is again subjected to evaporation from ebullition. When it is transported by cars, oil is transferred by overshot connections; when the car is filled, the conditions are those of small protected tanks during transportation, and the oil is subjected to ebullition when the car is emptied.

In this investigation, representative conditions of the five classes of conditions cited have been covered. Although the rate of evaporation per unit of time for each follows in the order given, the wide differences in the average time for carrying out each of the above operations changes their rank as regards total loss in each. (See Table 23, p. 85.) For instance, even should 1 per cent be lost in filling a lease tank from an overshot connection in 24 hours, and only four-tenths of 1 per cent of volume be lost during the first 24 hours of storage in the lease tank, yet as the oil is kept in the lease tank for an average of five days the total loss is about 1½ per cent, or half again as much as the loss during the filling of the tank by overshot connections.

METHOD OF DETERMINING LOSSES.

FIELD WORK.

Two methods of determining evaporation loss were used, field measurements and distillation in the laboratory of oil before and after it was subjected to evaporation. Work in the field comprised the accurate measurement of a volume of oil (reduced to 60° F.) before being subject to a certain test of conditions, and a similar measurement at the end of the test. For example, to determine the loss in filling a lease tank, the oil was measured so as to obtain its exact volume at 60° F. before it flowed into a lease stock tank. After such flow had taken place, the gain in the amount of oil in the latter tank was again measured and reduced to 60° F. The difference between the gain in the stock tank and the measured amount flowed in represented the evaporation loss. In studying loss during storage in large tanks, the total amount of oil in a tank was measured semimonthly and the volume at 60° F. was calculated. The losses were computed periodically and an average loss determined. Similar procedure was applied to every experiment.

The data kept for each test were: Depth of the oil, temperature of the oil, and measurement of the tank for its net volume. In addition, a 2-quart average sample of the oil studied was taken for distillation in the laboratory.

Table 1 is a form for keeping field data and for making calculations to obtain evaporation losses. This form is headed "Lease storage,"

TABLE 1.—*Form of keeping field notes and making calculations to obtain evaporation loss at a lease storage-tank.*

Experiment: D-18.
Company: Number 1377.

Date filled: September 19, 1919.
Kind of tank. Steel-bolted, lease storage.

Roof: Steel.
Protection: None.
Size: 500 barrels.

Date.	Hour.	Position.	Fluid depth.	Average depth of fluid.	Oil temperature.				Temperature factor.	Temperature correction.	Volume of fluid.		Cumulative evaporation loss.		Sample.		
					Bottom.	Middle.	Top.	Average.			Actual.	At 60° F.			Gravity.[a]	Temperature.	Can No.
1919.			*Ft. in.*	*Ft. in.*	*° F.*	*° F.*	*° F.*	*° F.*		*Bbl.*	*Bbl.*	*Bbl.*	*Bbl.*	*Per ct.*	*° B.*	*° F.*	
Sept. 9	1.55 p. m.	A	16 $\frac{13}{16}$	16 $\frac{5}{8}$	80	81	81	80.6	1.00906	4.4	487.6	483.2	0	0	39.5	93	237
		B	16 $\frac{3}{8}$														
		C	16 $\frac{11}{16}$														
10	10.10 a. m.	A	16	15 11$\frac{7}{8}$	81	82	82	81.6	1.00949	4.6	485.0	480.4	2.8	.58	....	....	....
		B	15 11$\frac{5}{8}$														
		C	15 11$\frac{7}{8}$														
11	11 a. m.	A	15 11$\frac{1}{4}$	15 11$\frac{1}{16}$	81$\frac{1}{2}$	82	82	81.8	1.00958	4.6	483.7	479.1	4.1	.85	....	....	....
		B	15 10$\frac{7}{8}$														
		C	15 11$\frac{1}{8}$														
12	11.30 a. m.	A	15 10$\frac{1}{16}$	15 9$\frac{15}{16}$	79$\frac{1}{4}$	79$\frac{1}{4}$	80	79.5	1.00858	4.1	480.9	476.8	6.4	1.33	....	....	....
		B	15 9$\frac{3}{4}$														
		C	15 10														
13	2.20 p. m.	A	15 9$\frac{1}{4}$	15 9	76$\frac{1}{2}$	77$\frac{1}{4}$	78	77.1	1.00752	3.6	478.5	474.9	8.3	1.72	....	....	....
		B	15 8$\frac{3}{4}$														
		C	15 9$\frac{1}{8}$														
14	9.45 a. m.	A	15 8$\frac{11}{16}$	15 8$\frac{9}{16}$	73	75	75	74.4	1.00634	3.0	477.4	474.4	8.8	1.82	....	....	....
		B	15 8$\frac{3}{8}$														
		C	15 8$\frac{5}{8}$														
15	2.45 p. m.	A	15 8$\frac{13}{16}$	15 8$\frac{11}{16}$[b]	80	82$\frac{1}{2}$	82	81.5	1.00945	4.5	477.7	473.2	10.0	2.07	38.0	82	10
		B	15 8$\frac{1}{2}$														
		C	15 8$\frac{3}{4}$														
16	1.35 p. m.	A	15 8$\frac{9}{16}$	15 8$\frac{7}{16}$	80	81	81$\frac{3}{4}$	81.0	1.00923	4.4	477.1	472.7	10.5	2.18	....	....	....
		B	15 8$\frac{1}{4}$														
		C	15 8$\frac{1}{2}$														
17	3.40 p. m.	A	15 8$\frac{7}{16}$	15 8$\frac{5}{16}$	78	78$\frac{1}{2}$	78$\frac{1}{2}$	78.4	1.00810	3.8	476.8	472.0	11.2	2.32	....	....	....
		B	15 8$\frac{1}{8}$														
		C	15 8$\frac{3}{8}$														

[a] By hydrometer in the field.

[b] It rained between Sept. 14 and 15.

Notes.—Filled at 1 p. m. Flat roof; one 20-inch hole at center, open; two 8-inch openings, one on either side, closed, but not tight enough to exclude any rain water that might collect. All valves and gates pertaining to this tank were checked and no leaks observed. Tank appeared in good condition, except roof. Discharge gates were locked. Estimated that 50 per cent of rainfall on roof leaks into tank.

but may be applied to any experiment by change of heading. An examination of the measurements for a test at a lease storage tank shows exactly what happened to that tank of oil during this period. Temperatures were always taken at three points in a tank. Similar detailed records were kept for every test. In determining the depth of a tank of oil it was necessary to measure in exactly the same place each time. To this end a point on the tank roof was marked and measurements taken from it at each gaging. To eliminate chances of error and to increase the accuracy of the measurement, three depth measurements were made. Under "Position," in Table 1, the three points for these depths are marked A, B, and C. Tables for the net volume of a tank have been given by Bowie.[1]

LABORATORY WORK.

The second method of determining the percentage of loss was by distillation. At the beginning of any field test, a 2-quart average sample of the oil under examination was taken; periodically during the test and at the end of it similar samples were taken. The cans containing the oil were sealed to prevent evaporation, then sent to the laboratory for distillation. A description of the distillation apparatus is given on p. 26.

FORMULA FOR DETERMINING EVAPORATION LOSS.

Evaporation losses increase the specific gravity of a crude oil. If the specific gravity at the beginning and that at the end of the test, and the specific gravity of the part that has evaporated are known, then by formula the percentage of the volume lost may be determined. Or, if the percentage that has evaporated and the specific gravities of the crude before and after evaporation are known, the specific gravity of the portion evaporated may be determined. This may be worked out as follows (note that gravity in degrees Baumé must be reduced to specific gravity):

Let d_1=specific gravity of the crude before evaporation takes place.
d_2=specific gravity of the crude after evaporation.
d_3=specific gravity of the portion lost through evaporation.
x=proportion of the original volume that was lost.
V=volume of the crude before evaporation takes place.

Then,
$1-x$=proportion of the volume remaining after evaporation.
$(1-x)V$=actual volume of the crude remaining after evaporation.
Vx=actual volume evaporated.
$d_1V=W_1$=weight of the crude before evaporation.
$d_2(1-x)V=W_2$=weight of the crude after evaporation.

---

[1] Bowie, C. P., Oil-storage tanks and reservoirs, with a brief discussion of losses of oil in storage and methods of prevention: Bull. 155, Bureau of Mines, 1917, p. 59.

$d_3Vx = W_3 =$ weight of the portion evaporated.

Now, since the weight of the crude before evaporation must necessarily equal the weight of the crude after evaporation plus the weight of the portion that is evaporated

$W_1 = W_2 +{}_3$ or, W_3

$d_1V = d_2\ (1-x)\ V + d\ Vx$

The V's cancel and the equation when solved for x becomes

$x = \frac{d_2 - d_1}{d_2 - d_3}$ and solving for d_3.

$$d_3 = \frac{d_1 - d_2\,(1-x)}{x}$$

This formula will be used with results of distillations to determine the percentage of volume lost. (For determination of the specific gravity of portion lost from the distillations, see p. 19.)

DISTILLATIONS.

Very small cuts were desired in the first part of the distillation. These were at intervals of 2 per cent to the first 19 per cent off, then 5 per cent intervals. In order to get enough distillate to take the gravity with a 2 per cent cut, 1,000 c. c. was used as a charge for the copper still. Figure 7 (see p. 36) shows the layout of the distillation apparatus.

Heat was applied to the still until the oil boiled. The vapors passed upward through a 10-inch Hempel fractionating column filled with small chain nearly to the vapor take-out. The thermometer bulb was placed in the fractionating column opposite this take-out and the temperature read at each cut. The vapors continuing passed downward through the condenser, and the resulting liquid was caught in a graduate surrounded by ice water. The gravity of the cuts was determined by a pycnometer for the 1 per cent cuts and by a hydrometer for the others. Distillation was made at the rate of 2 to 3 drops per second.

Table 2 shows the complete record for a single sample. When the sample was taken in the field the data shown opposite "Sample taken," were written on a tag and attached to the can. This eliminated all possibility of samples being mixed.

TABLE 2.—*Form for keeping distillation records on evaporation work.*

EVAPORATION EXPERIMENT.

[Laboratory record.]

Sample taken	From, Houston	Empire 1655. Prairie 82910.
	Date, August 24, 1919.	
	Hour, 2.30 p. m.	
	Gravity: At 80° F., 33.2° B. At 60° F., 31.8° B.	
	By D. S. Foster.	
	Can No., 260.	

Distilled
Date, October 18, 1919.
Gravity: At 64° F., 31.6° B. At 60° F., 31.4° B.
By S. M. Law.

Over point=236° F.

Per cent over	Temperature, ° F.	Gravity.
1	295	57.8
2	310	56.1
3	317	55.2
4	324	54.6
5	330	53.85
7	342	53.1
9	352	52.2
11	362	51.2
13	373	50.1
15	384	48.9
17	395	47.9
19	407	46.9
24	437	45.0
29	470	42.7
34	498	40.9
39	526	39.2
44	549	37.7
49	575	36.1

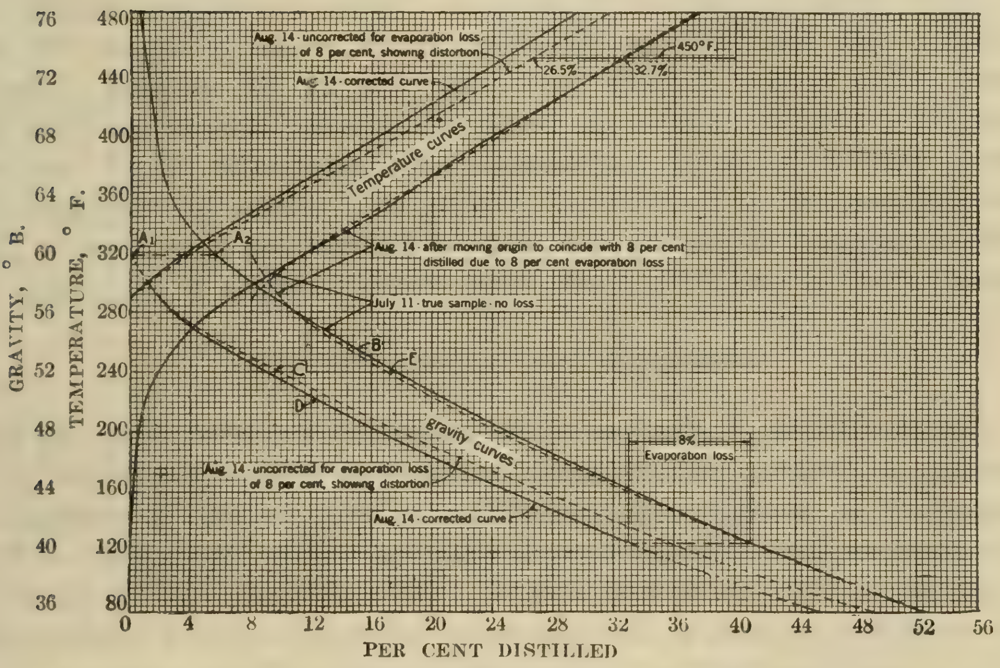


FIGURE 2.—Curves plotted from distillation data of samples taken from same tank of oil on two different dates, the first before evaporation and the latter after an evaporation loss of 8 per cent.

PLOTTING OF DISTILLATION DATA.

Distillation data were plotted as in figure 2 with the per cent distilled as abscissas and the degrees Baumé of the cut as ordinates. On the same sheet and with the same abscissas another curve was plotted with the temperature of the cut as the ordinates. This applies to the sample taken at the beginning of a test. Distillation data of a subsequent sample were plotted similarly and on the same sheet, with a correction applied to the per cent distilled, as explained below.

In plotting gravities it is necessary to place the point at the average of each increment, thus: The 1 per cent cut should be plotted at the ½ per cent point, the cut between 1 and 2 per cent at the 1½ per cent point. Now, if the next cut were between 2 and 4 per cent, then this reading should be plotted at the 3 per cent point, and so on. When very small cuts are taken little change will be shown in the shape of the curves.

Figure 2 embodies distillation data of two samples from the same tank, one taken on July 11 and the other on August 14. The "gravity per cent" curves have been lettered B, C, D, and E.

B represents the sample of July 11, true and correct.

C represents the sample of August 14, uncorrected.

D represents the sample of August 14, after correction.

E represents curve D after it is moved to the right 8 per cent or the amount of the evaporation loss.

First, consider curve B of July 11. This represents a tank of oil when it has lost nothing; in other words, when it equals 100 per cent. The dotted gravity curve for August 14, marked "uncorrected" (curve C), shows the result of a similar distillation with the same number of cubic centimeters, after this tank of oil has lost about 8 per cent of its volume. Owing to this loss, an improper distortion results, shown by the lack of parallelism (as along a line parallel to the axis of the abscissas) between curve B and curve C.

CORRECTION FOR DISTILLATION DATA.

Before further discussion of the methods of determining the percentage of volume lost through evaporation from distillations, it is necessary to assume that the effect of evaporation is practically the same as that of very slow distillation. (For discussion of this point see p. 92.) Now, assume that 1,000 c. c. represent 100 per cent of the oil in the tank at the beginning, and that by the later date the oil has lost 8 per cent of its original volume. If the 1,000 c. c. had been exposed to evaporation 920 c. c., or 92 per cent of the original oil, would be left. If the 1,000 c. c. had been distilled until 8 per cent were over, again only 920 c. c. would be left. If distillation were continued the succeeding cubic centimeters distilled would be charged against 1,000 c. c., the original quantity. If comparative results were to be directly obtained from a distillation of a sample of the later date (after 8 per cent had been evaporated from the tank), then this same number of cubic centimeters—920—should have been used and the number of cubic centimeters distilled charged against 1,000 for the per cent cut, just as in continuing the distillation.

It is, however, impossible to know what percentage of the volume is lost until the distillations have been compared; therefore the same number of cubic centimeters—1,000—were always run. True comparative results can be obtained by multiplying the percentage distilled by $(1-x)$, x representing the portion evaporated. For 8 per cent loss, the percentages distilled would have to be multiplied by 0.92 or 92 per cent. The result of plotting the gravity curve of August 14 with these new percentages distilled (curve D) is that this gravity-per cent curve parallels (along the ordinates) that of July 11 (curve B). In order to emphasize this parallelism, curve D was moved to the right 8 per cent, where it gives the dotted curve, E, marked "Aug. 14," after moving origin to coincide with 8 per cent distilled due to 8 per cent evaporation loss. Curve E, then, theoretically should coincide with curve B of July 11. Although coincidence actually is not exact the results are as close as can be expected from such work.

The correction, percentage distilled, as applied above to the gravity of a fraction, apply to the boiling points of the fractions in the same way.

THREE METHODS OF DETERMINING EVAPORATION LOSS FROM DISTILLATIONS.

1. SPECIFIC GRAVITY FORMULA.

The following method of obtaining the loss by formula obviates the necessity of making the correction on the percentages distilled. As the correction on curve C of August 14 at 1 per cent distilled is very small, the continuation of either curve C or D to zero will differ very slightly. From A_1, the point where these curves cut the zero per cent line, draw a line parallel to the axis of abscissas until it cuts curve B (July 11); that is, at A_2. Then the gravity of the portion lost is represented very closely by the part of the curve lying above A_2, and the average of that part of the curve will give a close approximation of the gravity of the portion lost through evaporation, which equals d_2 in the formula. (See p. 15.) An average of such a part of a curve may be obtained by taking points along it at equal intervals of abscissas and averaging them. (Baumé degrees are to be changed to specific gravity for the formula.) The formula will now give the percentage of volume lost very closely, since d_1 and d_2 should have been determined for the crudes before distillation. It is important that d_1 and d_2 should be determined accurately, for a small error in them makes a larger error in x, but a considerable error in d_3 causes a much smaller error in x.

Table 3 is a form for determining the percentage lost by the formula.

TABLE 3.—*Form for determining evaporation loss by formula.*

[Formula $x=\frac{d_1-d_2}{d_3-d_2}$=fraction lost.]

Date.		d_1		d_2		d_3		d_1-d_2	d_3-d_2	x
From—	To—	° *B.*	Sp. gr.	° B.	Sp. gr.	° B.	Sp. gr.			
										P. ct.
Sept. 19, 1919	Oct. 19, 1919	35.2	0.8475	33.7	0.8552	77.2	0.6757	0.0077	0.1795	4.29

2. TEMPERATURE—PERCENTAGE DISTILLED DATA.

A certain proportion, call it a, of the fresh oil distills at a given temperature, whereas oil that has been exposed to evaporation yields only b per cent of distillate at the same temperature. If x represent the proportion lost, then the correction previously described on page 19 must be applied to b in order to get a true comparison of percentages. The true comparative percentage distilled from the sample after evaporation is $b\ (1-x)$. The portion lost, then, is $x=a-b\ (1-x)$

whence $x=\frac{a-b}{1-b}$.

This will be termed the "temperature" formula.

In figure 2 consider the 450° F. point:

$a=32.7$ per cent $\qquad b=26.5$ per cent

$$x=\frac{32.7 \text{ per cent}-26.5 \text{ per cent}}{100 \text{ per cent }-26.5 \text{ per cent}}=\frac{6.2 \text{ per cent}}{73.5 \text{ per cent}}=8.4 \text{ per cent.}$$

3. GRAVITY OR TEMPERATURE CURVES.

The percentage lost may be determined approximately by inspection from curves B and C of figure 2, by measuring the distance from A_1 to A_2 in percentages. Using this percentage loss, the distillation curves of August 14 may be corrected as explained previously. The gravity curves only are to be considered first. Curves B and D give a third or graphic method of determining the percentage loss. If the corrected curve is parallel, along the ordinates, to the original one, the determined loss is correct. If not, a second estimate can be made and the curve corrected a second time and replotted. (After the first correction is made in a number of instances the loss by inspection will be very close.) Now there may be considered a line parallel to the axis of abscissas which is cut by the correct gravity curves of both dates. The number of per cent between the two points where this line is cut, first curve B of July and, second, by curve D of August 14 should give the per cent lost as found by the formula. One such result is represented by the 8 per cent evaporation loss noted in figure 2. A number of such operations should be averaged for accurate results.

This method tends to smooth out experimental errors and should therefore give the most dependable results. If results from the graphic method do not check those from the specific-gravity formula, there is probably some error in determining the specific gravities of the crudes, since that is the point of the greatest probability of error, if the sampling has been done properly. Similar treatment of the temperature curves will also give the per cent evaporated. The graphic method involves basic principles of the second method (temperature—per cent distilled), but as this third method is a graphic summation of a number of operations, each like the second, and this is applied to both temperature and gravity data, it has been classed separately.

COMPARISON OF METHODS.

In discussing the relative values of these three methods, the following points should be noted:

1. In applying the formula, the percentage of volume lost can be found if only the first two points on the "gravity" curves and the specific gravities of the crudes on the two dates are known.
2. The method described under "temperature" may be used if only a single cut were made for each group of samples at the same temperature without the gravity reading. This temperature should be taken far above the point at which the first drop comes over, however.
3. The graphic method acts as a check on itself and actually gives the average result of a large number of calculations. It also visualizes in a very striking way the evaporation loss.

If all the data necessary for the third method were available, then the second method could be used, but the additional data on the gravities of the crudes would still be necessary for the first method. With barely enough data available for either method 1 or 2, then only method 1 or 2 could be used. A combination of all three methods should give accurate and dependable results.

If the percentage of volume lost and the specific gravity of the crude before and after evaporation are known, then by use of the formula the specific gravity of the portion evaporated can be determined.

The three methods from distillation plus the field method give a total of four.

Table 4 shows typical comparative results of the four methods of determining per cent loss due to evaporation. That the field measurements show a slightly lower loss than the laboratory results is probably caused by insufficient allowance having been made for rainfall leakage, such leakage settles to the bottom of the tank and raises the fluid level. It is practically impossible to tell exactly how much a roof leaks per inch of rainfall, but the allowance made was conservative. As noted in this table, all of the experiments recorded in this bulletin were checked.

In laboratory work all the distillations of a single experiment should be made with the same apparatus and in the same manner.

TABLE 4.—*Typical results of four methods of determining loss per cent due to evaporation.*

Experiment No.	Dates.		Loss per cent.			
	From—	To—	Specific gravity formula.	Graphically.	Temperature data.	Field.
	1919	*1919*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
6	July 10	Aug. 23	8.35	10.00	6.30	9.46
7	July 12	Aug. 25	10.40	11.50	12.90	10.52
8	July 11	Aug. 14	5.43	6.50	6.00	6.14
9	...do.....	Aug. 24	9.45	9.00	9.20	8.31
10	...do.....	Aug. 14	7.19	7.00	6.50	6.67
11	July 10	Aug. 23	7.95	7.70	8.00	7.36
15	Sept. 9	Oct. 19	4.29	5.00	4.33	3.70
16	Sept. 17	Oct. 27	11.37	11.70	11.70	11.33
17	Sept. 10	Oct. 15	1.64	1.45	1.63	1.50
19	Sept. 22	Oct. 27	3.93	4.60	4.18	3.60
20	Sept. 14	Oct. 24	10.17	10.65	10.66	9.37
21	Sept. 10	Oct. 15	8.45	7.55	6.83	8.90
22	Sept. 14	Oct. 24	6.30	6.50	7.65	5.72
23	Sept. 15	Oct. 5	6.39	6.70	7.26	5.90
Average	....	....	7.23	7.56	7.37	7.03

SOURCES OF ERROR.

PERSONAL ERRORS.

Instrumental errors should be eliminated by checking or calibrating, but two other classes of errors are possible in this kind of work. The first includes personal errors, such as misreading a depth or a temperature in the field, or improperly determining gravities, temperatures, or percentages in the laboratory. In order to eliminate personal errors a number of readings of depths and temperatures were always taken. The same man started and completed a single experiment, and one man made all of the distillations. Enough samples were taken to duplicate the work.

ERRORS OF METHOD DUE TO TEMPERATURE INCREASE.

The second source of error is in the method used for making calculations as affected by increased temperature, including the expansion of steel tanks and measuring tapes, and thermal expansion of the oil.

EXPANSION OF STEEL TANKS AND MEASURING TAPES.

Although the measurements and calculations needed to obtain the volumetric contents of the tank are made by men who specialize in this work, these can not always be accurate, because of the expansion of steel tanks and steel measuring tapes with rise in temperature. This charge is negligible, in fact, too small to read for small lease tanks or other small storage tanks, but is appreciable for 37,500 and 55,000 barrel tanks.

With increased temperature, both expansion of the circumference and of the measuring tape are changes in the same direction; that is, for an increase of 1° F. there is a correction due to the circumferential expansion, which is additive, and one for the expansion of the tape, also additive. With a 1-degree rise in temperature a 55,000-barrel tank has a volumetric increase of 0.655 barrel, due to the increase of circumference only, while the measuring tape would expand enough to cause an error of plus 0.368 barrel. These two errors added give 1.023 barrels. The similar correction for a 37,500-barrel tank is plus 0.67 barrel per degree Fahrenheit. For a 1-degree rise in temperature this error is much smaller than would be warranted by the closeness with which the volume in the tank at 60° F. can be determined. For 20°, 30°, or even 50° difference in temperature, however, it amounts to a corresponding number of barrels, which is measurable. This correction was made in all the measurements of large tanks.

THERMAL EXPANSION FACTOR OF OIL.

The factor used for calculating the expansion of the oil with temperature increase is another possible source of error. Within very narrow limits, it might be said that every oil has a different coefficient of thermal expansion, but the Bureau of Standards has made a thorough investigation of this subject and has published factors for oils of different gravities. Technologic Paper 77 [2] of that bureau is particularly valuable for reference; the factors used in this report were taken from it. On page 19 of that paper is a table showing the variation of this factor for petroleums. For further information on the subject, see Circular 57 of the Bureau of Standards.[3]

In determining the volume of large tanks, 5,000 barrels and more, it is important to have a close average temperature of the contents. The volumetric error introduced by 1° F. error in temperature for a filled 55,000-barrel tank is 24 barrels. To reduce this error as much as possible, temperatures were taken at three points in a tank. Some special work was done on 55,000-barrel tanks to determine the possible accuracy in obtaining the average temperature (see p. 77), a special thieving thermometer being designed and constructed for that purpose. This and other apparatus will be described in the following pages.

---

[2] Bearce, H. W., and Peffer, E. L., Density and thermal expansion of American petroleum oils: Bureau of Standards, Technologic Paper 77, 1916, 26 pp.

[3] United States standard tables for petroleum oils: Bureau of Standards, Circular 57, 1916, 64 pp.

APPARATUS USED IN DETERMINING QUANTITY OF OIL.

MEASURING TAPE.

Almost always the depth of the fluid was determined by the standard steel gaging-tape, which is 33 feet long with a heavy plumb bob at one end. This tape is lowered into the oil rapidly until it approaches the bottom of the tank; then the rate of lowering is decreased until the tape barely moves. After the plumb bob has lightly touched the bottom, the tape is quickly wound up until oil first shows on the tape. At least three readings are taken at every point. If the bottom has so much B. S. on it that a good touch is impossible, the difference in the depth of oil during the test is determined by measuring from some point marked on the roof down to the surface of the oil.

HOOK GAGE.

Another instrument used occasionally for determining the change in the depth of oil in a tank was the hook gage, consisting merely of a sharp-pointed hook on a short wooden gage-pole. This rod can be raised or lowered and is controlled by a collar with a set screw, the collar being fixed at some point on the roof. Although this device does not give the actual depth of the oil, it shows changes in depth very accurately.

TANK THERMOMETER.

For tanks of 1,600 barrels capacity or less, temperatures are taken with an ordinary small tank thermometer, which is merely a metal temperature scale attached to a wood back. The bulb of the thermometer is in a small copper cup with a large opening at the top, tacked to the lower end of the back. The large opening of the thermometer cup allows some interchange of oil while the cup is being raised from the bottom of a tank. In this case the same thermometer was used throughout a single experiment. All thermometers were calibrated to a standard instrument.

THIEVING THERMOMETER.

For use with 55,000-barrel tanks, a special thieving thermometer was devised. Figure 3 shows this in detail.

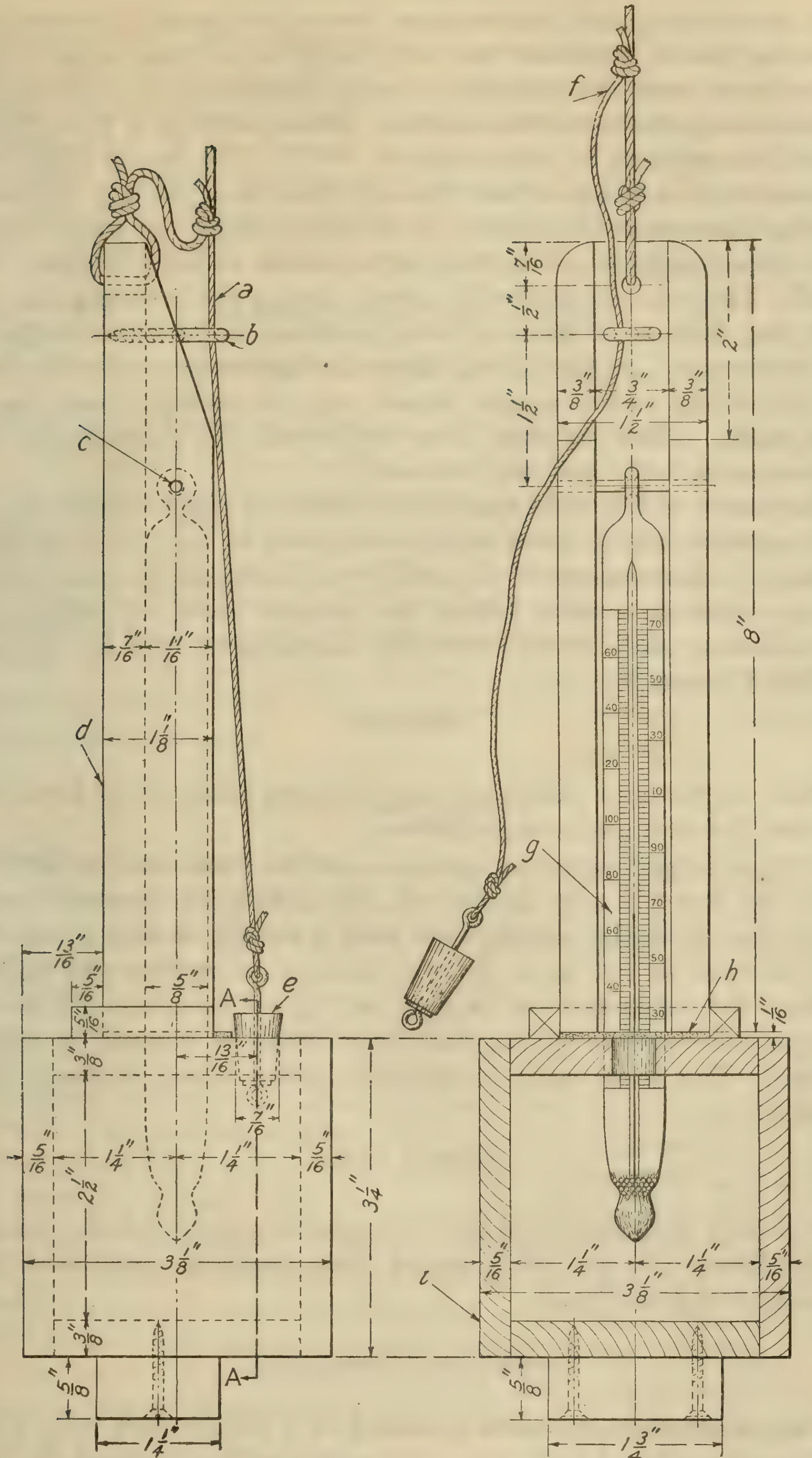


FIGURE 3.—Detailed drawing of thieving thermometer used to obtain accurate temperature readings at any depth of a tank of oil; *a*, cord with cork in place; *b*, screw eye; *c*, ⅛-inch wood pin; *d*, wood protector; *e*, cork; *f*, cord after jerking cork; *g*, thermometer with protected scale; *h*, 1/16-inch leather washer, squeeze fit; *i*, box made of wood or other nonconductor of heat.

In constructing this thermometer, two objects were to be attained. The first was to eliminate the interchange of oil that occurs while an ordinary tank thermometer is being brought to the surface, because in large tanks the temperature difference from 5 feet off bottom to the top may be as high as 6 to 10° F. The second object was to prevent an exchange of heat through the sides of the cup surrounding the thermometer bulb while it was being raised. In order to prevent interchange of oil the hole for entrance of oil was made very small. This was stopped with a cork during the lowering into the tank, the friction of the cork being sufficient to hold the weight of the instrument. At the desired depth the cork was removed by jerking the string and a sample flowed into the nearly closed cup at that point. After standing 15 to 20 seconds the thermometer was withdrawn quickly and read at once.

Insulation of the bulb was accomplished by constructing the cup of a material which is not a good conductor of heat, such as wood. With this thermometer it is possible to determine the temperature at any point in a tank within the possible limits of reading the thermometer used. Work with this thermometer will be discussed in Part II, page 76.

SAMPLER.

Many methods of obtaining samples from tanks of oil have been devised, but that used was as follows:

Place a 2-quart sampling can in a leather frame and weight this until the can will sink in the oil. To obtain an average sample, lower the can to the bottom, then raise it evenly at such a rate that the can will be not quite full by the time it reaches the surface. After a few trials this can be done with great accuracy. When the sample is brought to the top the cover should be screwed on tightly at once. This cover has a composition gasket which insures a tight joint.

SAMPLE CANS.

Ordinary rectangular soldered tin cans were used. Until shipped to the laboratory and while stored there awaiting distillation they were kept in a cool place.

DISTILLATION APPARATUS.

The distillation apparatus consisted of a copper flask with a distillation capacity of 1,000 c. c. of oil connected to a Hempel fractionating column. The vapor on leaving the column passed through a vertical condenser consisting of a staggered glass tube surrounded with ice water. The resultant liquid was collected in the graduate below, which was also immersed in ice water to decrease evaporation. This is a modification of the standard method of making distillations recommended by the Bureau of Mines, and was designed for the particular needs of the present investigation. Any slight variation in distillation apparatus would be just as effective, provided the same apparatus were used throughout all the experiments.

PRESENTATION OF RESULTS.

PERCENTAGE OF ORIGINAL VOLUME LOST.

Evaporation losses are shown in four principal ways. The first is by the percentage of the original volume which is lost through evaporation. At first it may seem incorrect to determine such a loss by percentage, because if the volume of oil stored were the same the manner in which it is stored would cause the percentage lost to vary greatly. For instance, if the area exposed for a unit volume were doubled, the percentage of the original volume lost will be much increased. As, however, the conditions under which such losses occur are fully described and defined, such a percentage can be considered as applying to these conditions only.

ACTUAL VOLUME LOST.

The second presentation is by the actual volume lost under any prescribed conditions. This volume is always shown in this report as barrels or gallons and gives a more vivid mental picture of the direct result of evaporation.

ACTUAL VALUE LOST.

The third method will be to show the actual value, in dollars, of the loss for the same conditions of storage as considered above. In calculating the value lost, the loss is considered primarily as gasoline at 22 cents per gallon. This is necessary because the loss is gasoline that would, if saved, have a market value equal to that of the best grade of gasoline available, since the effect of evaporation is that of a slow distillation in which fractionation is very good. Secondarily, the loss has been considered as crude at $3 per barrel. Although the loss is not crude oil, nevertheless, as far as the producer or pipe-line operator in the Mid-Continent field is concerned the effect is a reduction in the volume of his crude.

If, however, the oil were bought on the sliding-scale gravity basis, as in California, the producer would feel the loss both as one of quality and of quantity. Suppose, for instance, that 1,000 barrels of 35° B.

oil lost 5 per cent through evaporation. Then 950 barrels of oil of about 33° B. would be left. If the 35° B. oil brought $3.10 per barrel and the 33° B. oil $3 per barrel, then the loss would be $3.10×1,000—$3×950, or $3,100—$2,850, or $250. Without the sliding scale, that is, if both the 33 and 35° B. oil were worth $3 per barrel, the loss would be only 50×$3, or $150. Thus, with such a sliding scale, the producer, by suffering a 5 per cent evaporation loss, loses 50 barrels at $3 per barrel plus 10 cents on the 1,000 barrels. Therefore, if a producer prevents evaporation loss he should be rewarded by a better price for his crude than he formerly received.

PERCENTAGE OF VALUE LOST.

The fourth method of presenting results for the same conditions of storage and handling of the refined products mentioned is to show the percentage of loss in value of the original crude by evaporation.

As a barrel of oil leaves the well it has one price, which represents the gross income to the producer, and as it leaves the refinery it has another and much higher price, which represents the gross income to the refiner. Using these two values of crude as a basis and considering the part lost as having the value of gasoline gives two bases for the percentage of value lost; using the value of crude in the field as a basis and considering the part lost as crude gives still a third basis for computing the percentage lost. These three may be described as follows:

GASOLINE VALUE v. FIELD PRICE OF CRUDE.

The volume lost considered as gasoline at 22 cents per gallon, as against crude valued at $3 per barrel, represents the condition where the producer of the oil should save the vapor, turn it into gasoline, and sell it as such. Naturally, the cost of such saving must be subtracted from the value of the gasoline manufactured and sold. The gross percentage of value lost, considered alone, may be estimated as follows:

Method of estimating gross percentage of value lost.

Gasoline at 22 cents per gallon	per barrel	$9.24
Crude on lease at	do	3.00
1 per cent volumetric loss gives an actual value loss of		0.0924
The percentage of the total value lost is then		$\frac{0.0924}{3.00}=3.08$

Thus an evaporation of 1 per cent of the original volume causes a loss of 3.08 per cent of the original value.

GASOLINE VALUE V. PRICE OF REFINED PRODUCTS.

The loss considered as gasoline at 22 cents per gallon as against the value of refined products at $4.28 per barrel represents the condition if the refiner assumed such losses by evaporation. Assume that a barrel of oil gives the following products:

Fraction.	Product.	Value.
Per cent.		
25	Gasoline, at 22 cents per gallon, or $9.24 per barrel	$2.31
25	Burning oil, at 10 cents per gallon, or $4.20 per barrel	1.05
46	Fuel oil, at $2 per barrel	.92
4	Loss in refining	.00
100	Total	4.28

The gross income to the refiner is, therefore, $4.28. The evaporation loss is from the gasoline fraction.

Then 1 per cent volumetric loss means 4 per cent of the gasoline gone—value, $0.0924.

And 1 per cent volumetric loss gives the percentage value lost as $\frac{0.0924}{4.28}=2.16$ per cent.

Here an evaporation of 1 per cent of the original volume means a loss of 2.16 per cent of the original value.

CRUDE V. CRUDE AT ANY PRICE.

The loss considered as crude as against the value of crude at any price shows what percentage of the value lost the producer or pipeline operator assumes when he considers the commodity lost as having a value no higher than that of his crude. This loss is easy to estimate, for when it is considered as crude oil, the percentage volume lost equals the percentage of value lost.

A consideration of the percentage of value lost by evaporation emphasizes the fact that with crude oil this kind of loss has a doubly detrimental effect—a decrease in volume and a decrease in quality. When the loss as gasoline is compared with the loss as crude at $3 per barrel, the qualitative loss is greater than the quantitative loss. Consideration of loss as gasoline versus refined products at $4.28 per barrel shows that the loss in quality is just about as great as that in quantity. From the third consideration—loss as crude versus crude at any price—it is presumed (erroneously, of course) that there is no qualitative loss. A saving of evaporation loss, then, will have the double effect of increasing the quantity and quality of the gasoline produced in the United States.

PART II.—VOLUMETRIC LOSS FROM EVAPORATION DURING VARIOUS STAGES OF HANDLING.

INTRODUCTION.

NATURE OF TESTS.

As it is impossible to determine what the loss might be in every possible case, experiments were planned to cover the most important features and to represent, as nearly as possible, average conditions. The meager accounts of evaporation tests published to date represent either laboratory experiments or special conditions. In this report the author sought to avoid special conditions and to obtain results that apply generally. Field experiments were made with tanks, pipe lines, tank cars, and dehydration plants, just as they are used in practice. In other words, the tests were planned to show neither a very large evaporation loss nor a very small one.

The tests are grouped to show evaporation losses under the following conditions:

1. Dehydration by steaming.
2. Filling lease storage tanks.
3. Storing oil on the lease.
4. Storing oil in 55,000-barrel steel tanks.
5. Transferring oil from lease to refinery.
6. Filling large tanks through bottom connections.

A description of the layout and method of each test will be given, together with the presentation and discussion of results. The tests are apportioned as follows:

Apportionment of tests.

Type of test:	No. of tests.
Dehydration plants	4
Lease storage tanks	40
Filling tank by overshot connections	2
Large storage tanks	80
Tank cars	12
Filling tank by bottom connections	1

EVAPORATION LOSSES IN DEHYDRATION BY STEAMING.

CONDITIONS FOR MAKING TESTS.

A summary of the conditions under which the tests were made follows: Location—El Dorado Pool, Kans.; daily production of the lease—300 barrels; degrees Baumé of the oil—37.55; gasoline content of the oil—410° F. end point—30 per cent; length of test—36 hours; season—summer; weather conditions—average.

DESCRIPTION OF PLANT.

Dehydration of crude oil is necessary to remove emulsified water. The method largely used is to pass the oil through water heated by steam. This steam may be carried through a pipe to the bottom of the tank, where it is allowed to flow into the water and condense, or it may be taken to the bottom through a series of coils, then up and expelled into the air.

A few small concrete dehydrators using steam have been built. These were not tested for evaporation loss because they represent so small a proportion of those in use. The usual type is that sketched in figure 4. The oil and water are passed through *d*, a conductor pipe, which reaches from the top of the tank to a point somewhat below the bottom of the oil layer *f* in the first dehydrating tank. As the mixture bubbles up through the water it is heated, causing the globules of water in the oil to coagulate and settle. The oil gradually passes through this stage and by *i* into the second dehydrating tank, where it is treated similarly; from there it flows into the stock tank *o*. The measuring tank *b* on the scaffolding and the measuring tank *n* were set up for the test to determine evaporation losses.

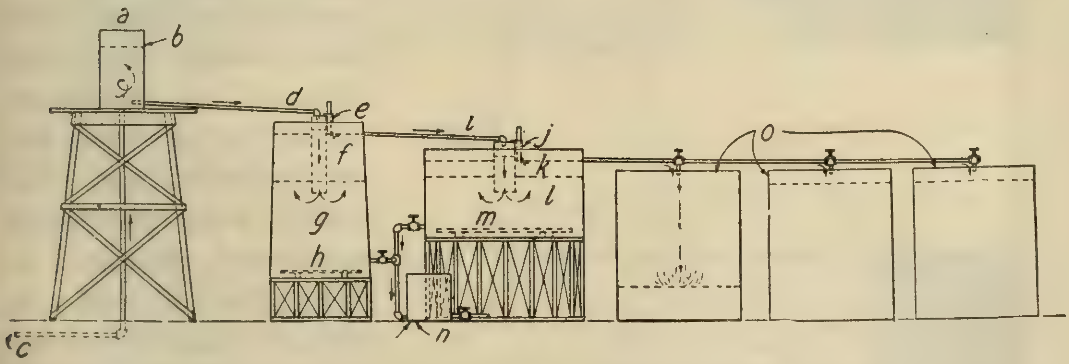


FIGURE 4.—Plant equipped for dehydration by passing emulsion through hot water: *a*, mixture of oil and water; *b*, measuring tank; *c*, buried lead pipe; *d*, first dehydration; *e*, hook gage; *f*, oil; *g*, water; *h*, steam coils; *i*, second dehydration; *j*, hook gage; *k*, oil; *l*, water; *m*, steam coils; *n*, water-measuring tank; *o*, stock tanks.

METHOD OF DETERMINING EVAPORATION LOSS.

As has been stated, such a plant was selected for tests because it represents average conditions. The general method of determining the loss was to measure accurately what went in and came out of the plant. For measuring the inflow two 25-barrel tanks (*b*, fig. 4) were placed in an elevated position on the scaffold. These tanks

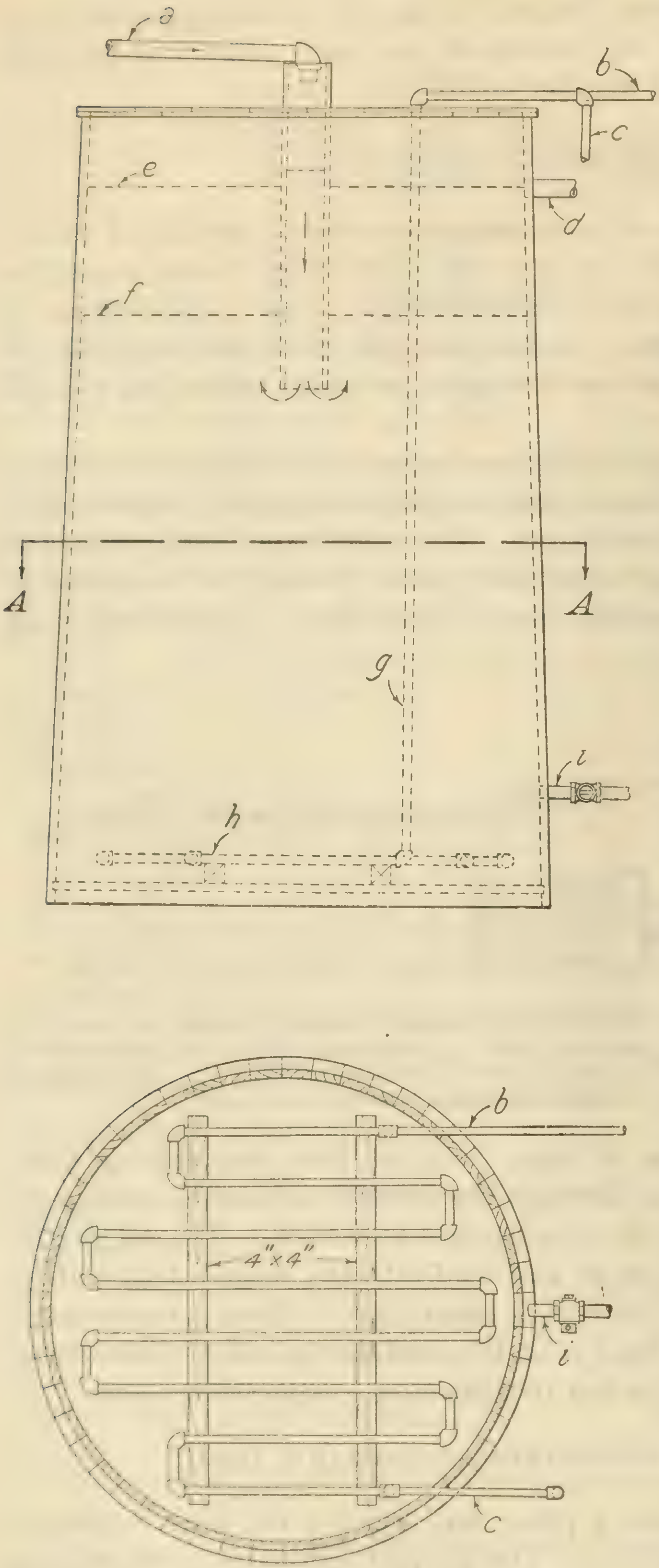
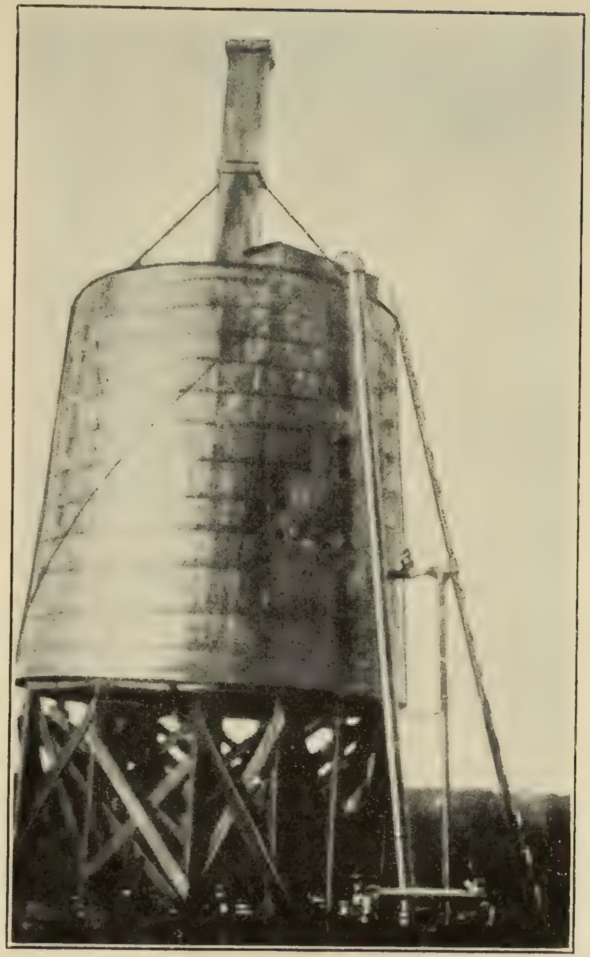


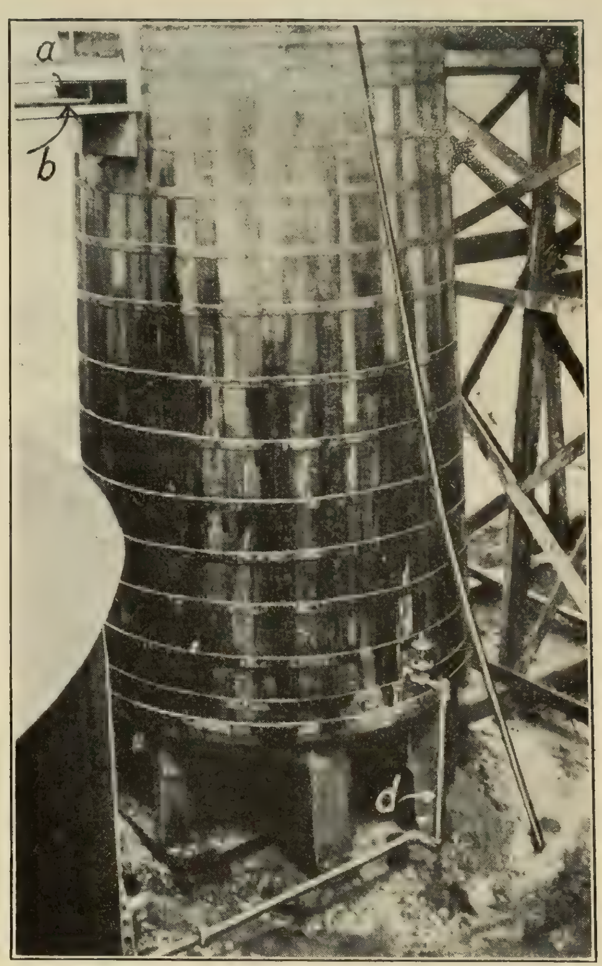
FIGURE 5.—Dehydrator tank, showing closed steam coils: *a*, 3 inch oil inlet; *b*, steam inlet; *c*, steam outlet; *d*, 3-inch oil outlet; *e*, oil level; *f*, water level; *g*, 1-inch pipe; *h*, steam coil; *i*, 2-inch water outlet.

were manifolded, as indicated in Plate II, *A*, in such a way that one could be filled while the other was being emptied and a change from one tank to the other made without stopping the inflow of oil. Plate II, *B*, shows method of filling tank cars.

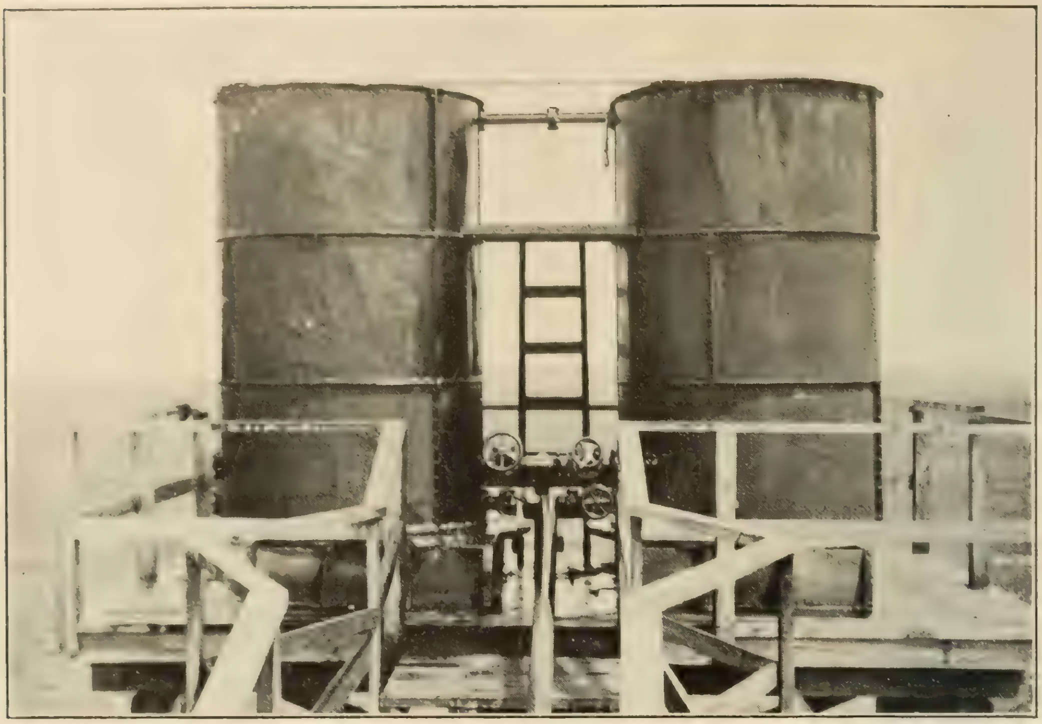
In order that no error might be introduced by steam flowing into the water in the tanks closed coils were installed, as shown in figure 5. After installation these coils were tested for leaks, for any leak would decrease the apparent loss from evaporation. The tanks were absolutely tight and remained so throughout the test. In order to take care of water settled from the oil the dehydrating tanks were tapped near the bottom and the outlets manifolded and run into another measuring tank represented in figure 4 by *n*. Two hook gages were installed, one in each tank, to determine at any instant the total amount of oil in the two steaming tanks. These gages were so arranged that the change in level of the oil surface in either tank could be determined to



A. FLOW TANK TO SEPARATE GAS FROM OIL. MIXTURE ENTERS AT TOP OF TANK; GAS OUT STACK, OIL OUT NEAR BOTTOM, AND WATER OUT BELOW OIL OUTLET.



B, FIRST STAGE OF DEHYDRATION: *a*, OIL OUTLET; *b*, STEAM INLET; *c*, SECOND STAGE TANK; *d*, WATER OUTLET.



A. TANKS USED FOR MEASURING THE VOLUME ENTERING DEHYDRATION PLANT DURING TEST.

B, LOADING TANK CARS.

the nearest thirty-second of an inch. Even though the oil level were approximately constant, there may be a change of an inch or two due to the change in rate of inflow into the plant. By this installation and by the measurement of oil in the stock tank with a steel tape it was possible at any instant to determine how much liquid had gone through the plant.

Plate III, *A*, shows the plant before the installation of any special apparatus, Plate III, *B*, the construction of the scaffolding and the enlarged stock tanks, and Plate III, *C*, the same plant from another angle after the measuring tanks and piping had been installed. Plate IV, *A*, shows the top of the first dehydrator tank in figure 4, and how the oil falls from the overshot connection through the wooden conductor, which reaches 6 or 7 feet into the tank. The top of the hook gage can be seen projecting from the small hole in the foreground. Plate IV, *B*, shows how the oil enters the second dehydrating tank. The small pipe carries the entering steam to the coil below. The top of the hook gage is seen between the steam pipe and the oil pipe. Plate I, *B* (see p. 32), shows the first dehydrating tank with the outlet steam pipe projecting over the roof. The water-outlet connections which lead to the water-measuring tank appear at the bottom.

TEMPERATURES RECORDED.

Temperatures were taken of the oil in the measuring tanks, and in each of the dehydrator tanks, of the vapor above the oil in each of the dehydrator tanks, of the oil in the stock tank, and of the atmosphere. These temperatures were taken approximately one hour apart. In addition, the depth of the oil in each of the dehydrator tanks was recorded. This depth was kept as nearly constant as possible to equalize the conditions of the test.

MAKING THE TESTS.

At first, measurements and temperatures were taken at all points necessary to give the total volume of liquid in the whole plant; then the volume of oil and water in the first measuring tank was determined and later the oil and water was allowed to flow into the plant at approximately the normal rate of production of the lease. By the time this tank had run out, the other was about full.

The first tank was shut off when the oil ceased to flow, and its depth and the temperature of the contents were taken. Immediately thereafter, another set of measurements was taken throughout all the tanks in use in the plant, to determine again the total volume of liquid therein. With no evaporation loss the increment of liquid in the plant should have been equal to the volume of liquid that had been passed into it from the first full measuring tank. Any difference showed the evaporation loss.

Next, the second full measuring tank was measured and its contents allowed to flow into the plant at a normal rate. This process was continued for 36 hours and represented one test. Although the flow of oil from each full measuring tank was in itself a short test, the impossibility of obtaining exact volumetric measurements made it advisable to sum a 36-hour run to get the average loss during the whole period.

In addition to the field measurements to determine volumetric losses, samples were taken at the same time of the oil in the measuring tank and at each successive stage. These were sealed and the percentage of volumetric loss determined, as before explained, by distillation and calculation. The results check the field determinations very closely.

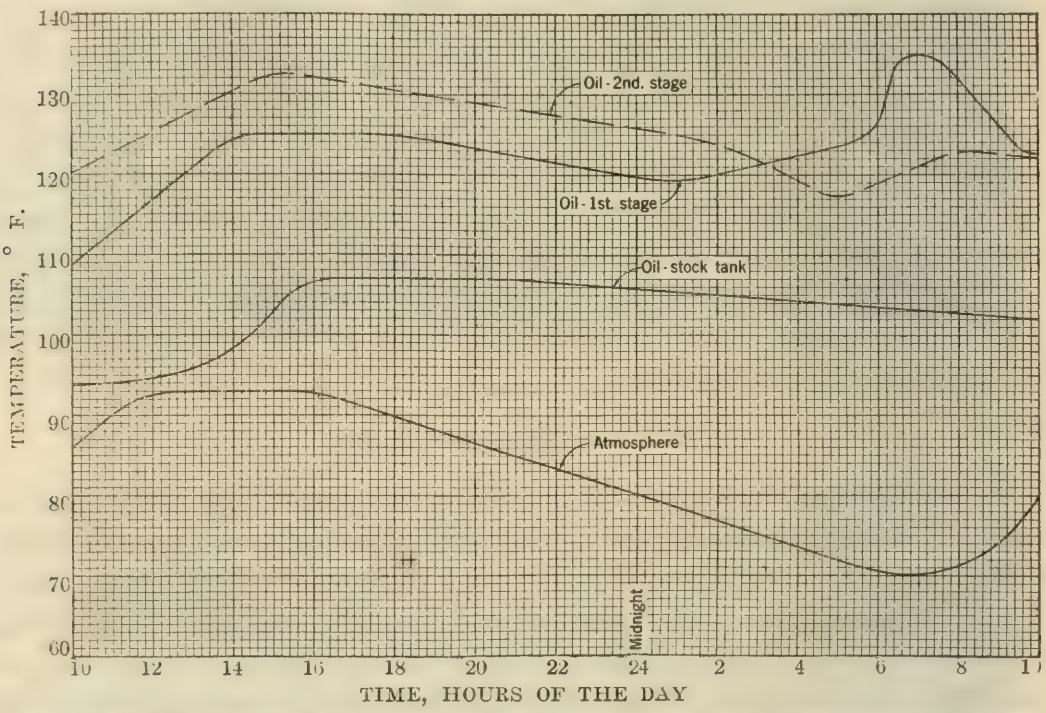
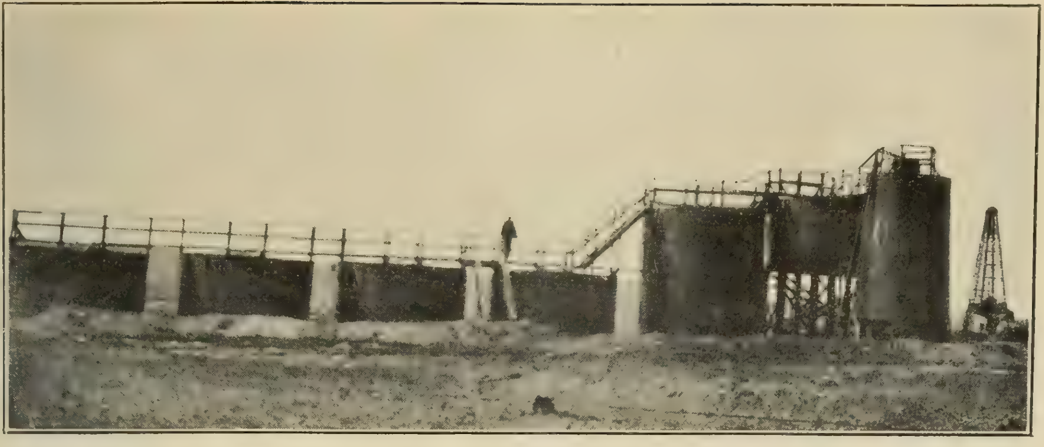


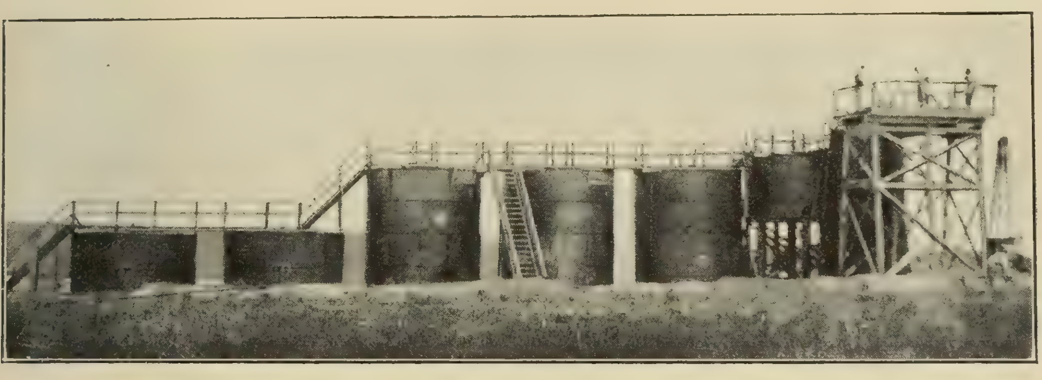
FIGURE 6.—Temperature conditions of third dehydrator test. Dehydrators average 125° F.

SCOPE OF TESTS.

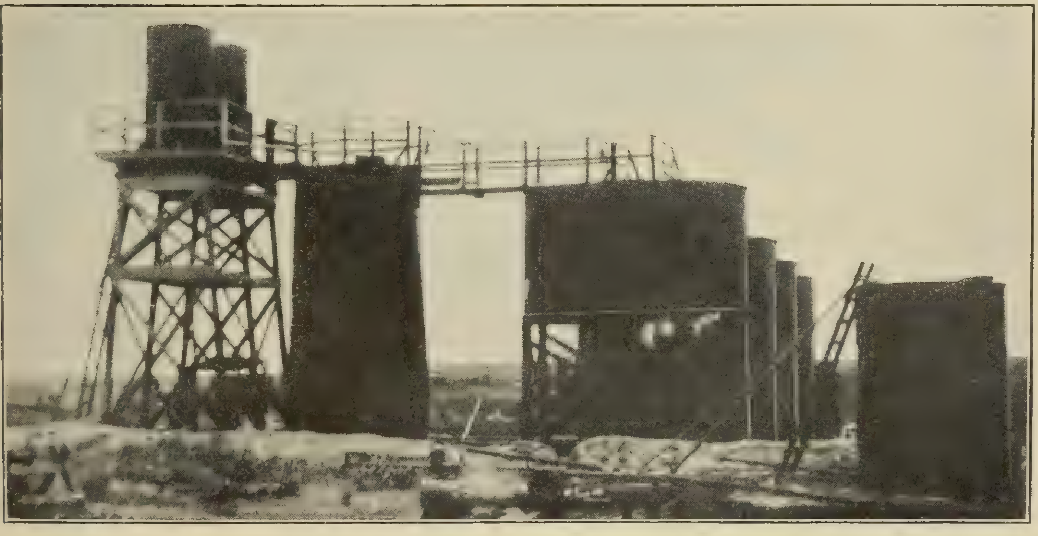
In order that as wide a range of conditions as possible might be covered four tests were run with a different temperature of the dehydrators in each at a plant handling an average daily volume of 300 barrels. The lowest temperature averaged 84° F. In this test no steam was forced through the coils in the dehydrating tanks. The second test was run at an average temperature of 105° F., the third



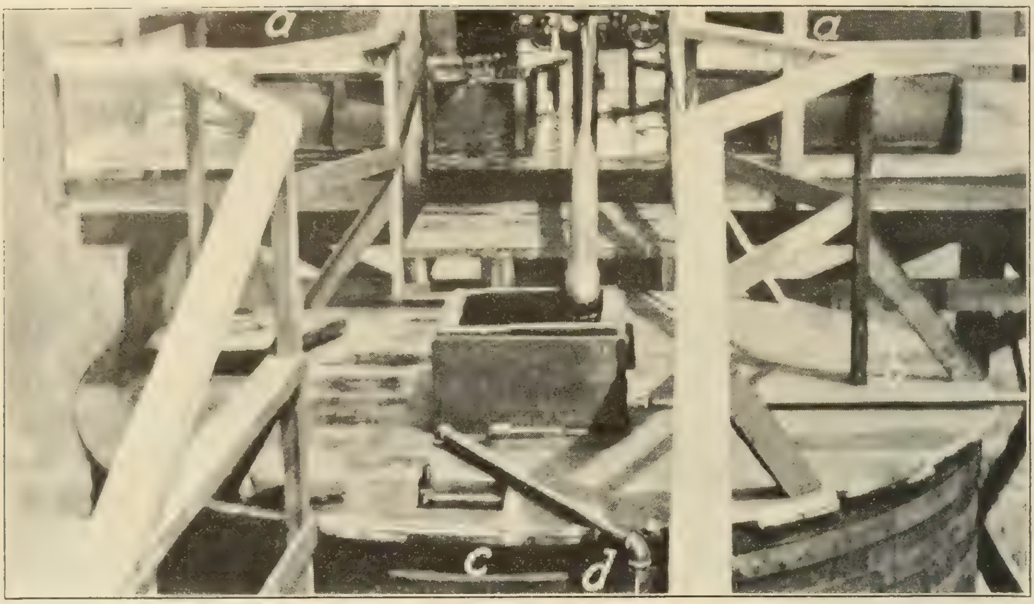
A, DEHYDRATOR AS USED BEFORE TEST.



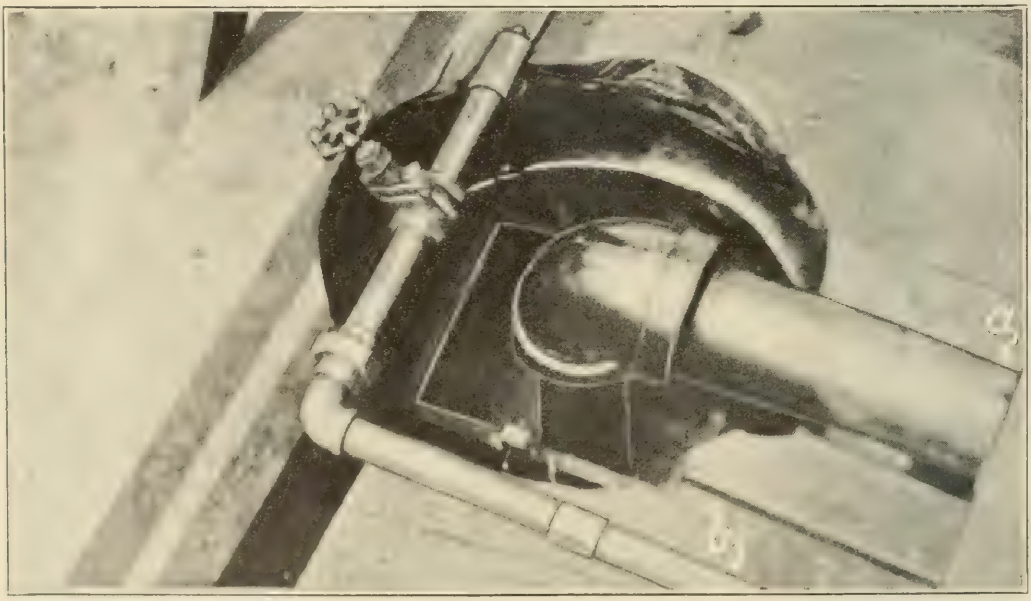
B, MEASURING-TANK SCAFFOLD ERECTED FOR DEHYDRATION TEST.



C, PLANT EQUIPPED FOR TEST.



A. FIRST STAGE OF DEHYDRATION, OIL ENTERING AT TOP: *a*, MEASURING TANKS; *b*, OUTLET OF STEAM PIPE; *c*, HOOK GAGE; *d*, INLET STEAM PIPE.



B, OIL ENTERING SECOND STAGE OF DEHYDRATION: *a*, OIL INLET; *b*, STEAM INLET.

at 125° F., and the fourth at 150° F. During all these tests there was absolutely no leakage in any of the tanks or in any of the connections.

The temperature conditions under which the tests were run showed considerable variation in the temperature of the dehydrators during a test especially at the higher temperatures. It is believed that the effect is practically the same as if they had been held at the average temperature.

Table 5 is an example of the measurements taken in deducing the evaporation loss. Under measurement of fluid entering is shown the total volume entering the plant. Under first dehydrator tank, second dehydrator tank, and lease storage tank are shown the total volume in the plant at specified stages. An increment between any two points of time determined from the summation of these three stages gives the total amount that passed through the plant. The difference between such increment and the measured entering volume represents the evaporation loss.

TABLE 5.—*Field data taken on dehydrator test, June 20, 1919.*

Measurement of fluid entering.					Last three stages.	First dehydrator tank.		Second dehydrator tank.		Lease storage tank.			
Tank No.	Hour.	Depths.		Temperature.	Hour.	Hook gage.	Oil temperature.	Hook gage.	Oil temperature.	Fluid depth.	Temperatures.		
		Full.	Empty.								Bottom.	Middle.	Top.
		Ft. In.	*Ft. In.*	°*F.*		*In.*	°*F.*	*In.*	°*F.*	*Ft. In.*	°*F.*	°*F.*	°*F.*
E-1	16.35	6 $6\frac{1}{8}$	....	73	....	....	....	....	....	....	....	....	....
E-1	17.25	....	0 $3\frac{1}{2}$	71	17.30	$3\frac{1}{8}$	110	$3\frac{1}{16}$	117	6 $5\frac{3}{8}$	92	98	105
E-2	17.35	5 $8\frac{3}{8}$	....	69	....	....	....	....	....	....	....	....	....
E-2	18.30	....	0 $3\frac{11}{16}$	70	18.35	$3\frac{1}{4}$	108	$3\frac{1}{16}$	114	6 $11\frac{9}{16}$	92	102	102

RESULTS.

Table 6 shows, in condensed form, the results of the four tests on this dehydration plant. These results have been analyzed and plotted in curves (figs. 7—10), each of which presents graphically a specified phase of the tests.

TABLE 6.—*Summarized results of dehydrator evaporation tests.*

Average temperature of dehydrators.	Test No.	Daily production.	Volume lost.		Gravity of portion evaporated.	Daily actual value lost.[a]		Per cent value lost.[b]			Gravity lost by crude starting at 37.55 °B.
						As crude.	As gasoline.	As gasoline— At 22c. per gal. v. crude at $3 per bbl.	As gasoline— At 22c. per gal. v. refined products at $4.28 per bbl.	As crude v. crude.	
° F.		*Bbls.*	*Per ct.*	*Bbls.*	*° B.*			*Per ct.*	*Per ct.*	*Per ct.*	*° B.*
84	1	300	1.76	5.3	80.3	$15.90	$49.00	5.4	3.8	1.76	0.65
105	2	300	3.30	9.9	78.0	29.70	91.50	10.2	7.1	3.30	1.10
125	3	300	5.45	16.4	76.9	49.00	151.20	16.8	11.8	5.45	1.55
150	4	300	6.70	20.1	73.1	60.30	185.80	20.6	14.5	6.70	1.95

[a] See p. 27.
[b] See p. 28.

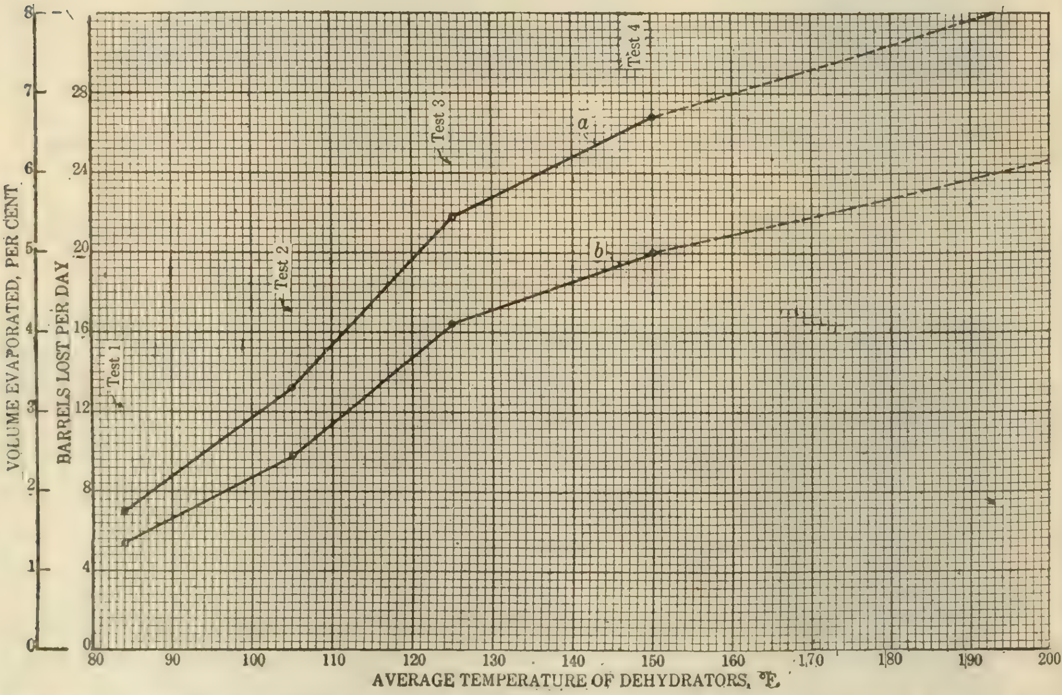


FIGURE 7.—Effect of temperature of dehydrators on volume lost: *a*, variation of percentage of volume lost with variation in temperature of dehydrators; *b*, variation of actual volume lost with variation in temperature of dehydrators.

Figure 7 shows the variation in the percentage of volume lost with the variation in the temperature of the dehydrators. This percentage increases at an almost constant rate until 125° F. is reached, where the curve tends to flatten because of the more rapidly evaporating fractions being eliminated in the early stages at such high temperatures; the heavier gasolines remaining evaporate at a much slower rate. It is well to notice that if this curve were projected to 200° F. for the temperature of the dehydrators the percentage of volume lost would reach as high as 8.5 per cent. As a matter of fact, 200° F. is not an uncommon temperature for these dehydrators.

Figure 7 also shows the effect of different temperatures—this time in barrels instead of in percentage of volume lost.

Figure 8 shows the rapid increase in value lost, considered as gasoline at 22 cents per gallon and as crude at $3 per barrel, as the temperature in the dehydrators increases. Figures 8 also shows the effect on the percentage of value lost as the temperature in the dehydrator rises. The lowest curve in this figure, loss as crude v. crude, represents the percentage of volume lost as well as the percentage of value lost. Examination of the other two curves shows how much the percentage of value lost exceeds the percentage of volume lost.

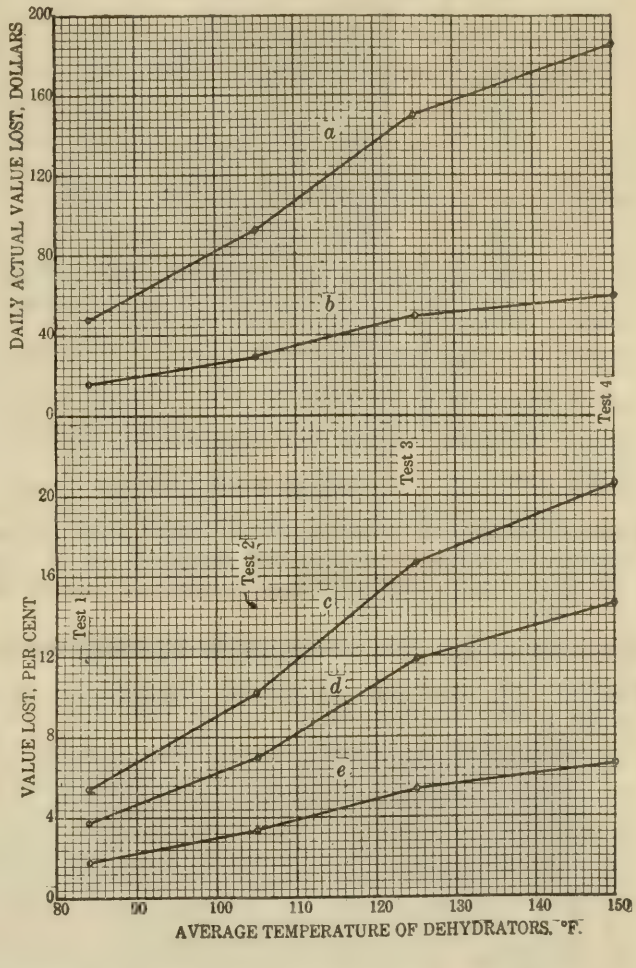


FIGURE 8.—Variation of actual value lost with increasing temperature of dehydrators, when loss is considered (*a*) as gasoline at 22 cents per gallon and (*b*) as crude at $3 per barrel; variation of percentage of value lost with increasing temperature of dehydrators, when loss is considered (*c*) as gasoline at 22 cents per gallon v. crude at $3 per barrel, (*d*) as gasoline at 22 cents per gallon v. refined products at $4.28 per barrel, and (*e*) as crude v. crude.

In figure 9, curve *a* shows the gravity of the portion evaporated for the different temperatures of dehydrators represented in four tests. At the lowest temperature, 84° F., the gravity of the portion that has evaporated is 80.3° B., but in the last test, that at 150° F., the average gravity of the fraction that has evaporated is 73.1° B. Naturally, the rate of evaporation of the lower fractions is much slower, even though at a higher temperature.

Another effect of heating oil is shown in curve *b* of the same figure. The incoming oil had an average gravity of 37.55° B. When the dehydrators were held at 84° F., the oil lost 0.65° B. while passing through the plant, and left it with a gravity of 36.9° B. at the end of the test. As the temperature was increased to 150° F., this loss rose as high as 1.95° B., the oil leaving with a gravity of 35.6° B.

The data presented in figure 7, when taken in conjunction with the specific gravity formula for percentage of volume lost, give a very close check on the volumetric measurements made in the field. As a matter of further interest, figure 10 has been drawn. In these

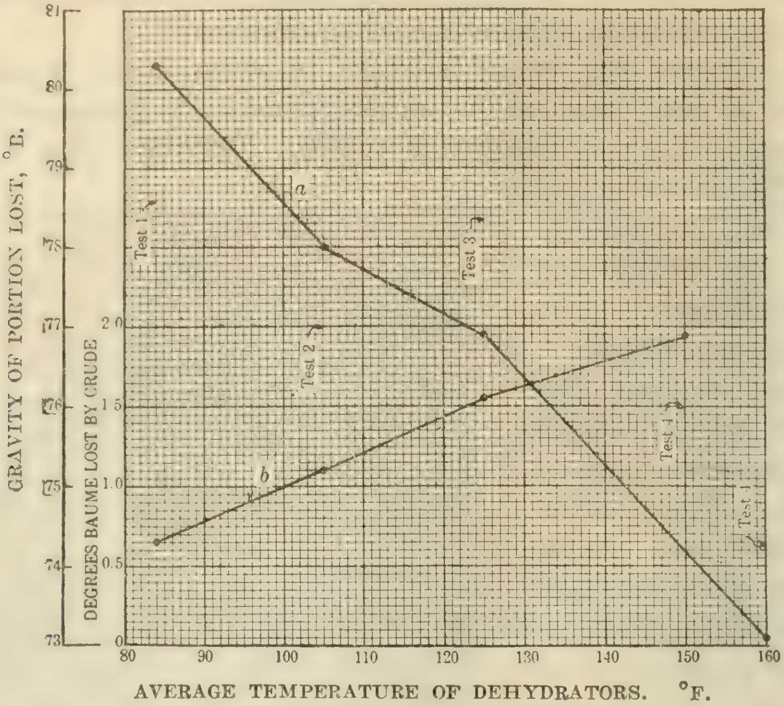


FIGURE 9.—Effect of temperature of dehydrators on loss of gravity of oil: *a*, gravity of portion evaporated at different temperatures of dehydrators; *b*, degrees Baumé lost by crude while passing through dehydrator at varying temperatures.

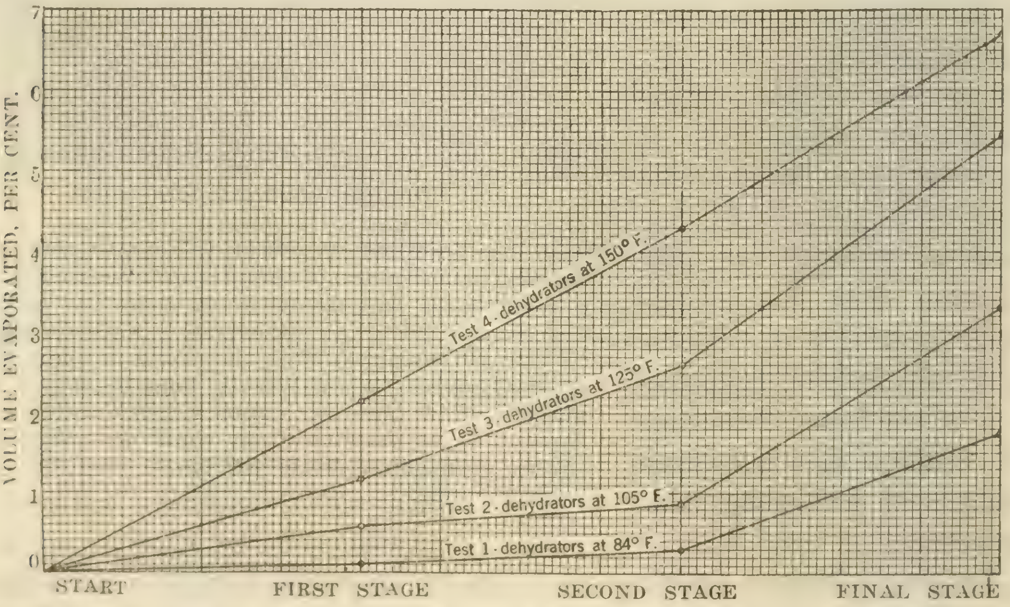


FIGURE 10.—Cumulative percentage of volume lost as the oil passes through successive stages of the dehydration plant.

curves, the percentage of volume lost has been taken as ordinates and the stages of the whole dehydration plant as abscissas, with an equal interval for each stage. Each curve represents the results of a single test. The depth of oil in the first and second dehydrator tanks was such that the oil remained in the first approximately two hours and in the second about six hours, making a total of about eight hours in passing through both. The average time spent in the third stage, or stock tank, during a 24-hour test would be 12 hours. Although ordinarily the temperature in the stock tank is much lower than in the dehydrators, still, as the oil spends more time in this stage and has farther to fall on entering the tank than in the other two stages, it would naturally be supposed that the greatest part of the loss would occur here.

For the lower temperature—84 and 105° F.—the loss in the third stage is very much greater than in either of the other two stages. At 125° F. the proportion of this loss has decreased, and at 150° F. it is shown to be much less than that in the second dehydrator tank. A combination of conditions causes this difference. The first condition of note is that the temperature of the third stage is much lower than that of the second stage for the 150° F. test. The next consideration is one that has been mentioned before—the lighter fractions evaporate in the first and second stages, leaving only the comparatively heavy gasolines to evaporate in the third stage.

GENERAL DISCUSSION OF DEHYDRATOR TESTS.

DISCUSSION OF ERRORS.

When these results are examined, it seems at first that an error may have been made in obtaining them. The fact that they are so large makes one pause to be absolutely sure that the work done is correct. As has been mentioned, each of these four tests is a combination of a number of small tests represented by each measuring-tankful that was run into the plant. Personal errors are thus eliminated, as each test checks the others. Not only was the professionally made tank gage-table used but check measurements were made to cover this point. The volumes of the measuring tanks for fluid entering were also checked thoroughly. The thermal expansion of the steel tank in the third stage, due to high temperatures and a possible wrong temperature-reduction factor for the oil itself had been considered and calculations made for possible errors from this source. The greatest possible combined error from these two sources was less than three-tenths of 1 per cent of volumetric loss.

In addition to these precautions, the percentage of volume lost was carefully determined from the distillations of the samples. These percentages checked the field results as closely as could be expected.

Another question that may throw doubt on the results is—why have the losses not been noticed if they are so large? The reason is that in dehydration plants the total liquid that a well or a lease makes is never measured. The net oil of a lease is measured only after it has passed through flow tank and dehydrator.

COMPARISON OF PLANT USED TO GENERAL CONDITIONS OF SUCH PLANTS.

The plant utilized for the tests does not represent conditions especially favorable to loss by evaporation, but as nearly as could be arranged approximates the average conditions prevailing in field plants dehydrating by steaming. In fact, care was taken that this plant should represent such plants at their best. To this end, the roof of the tank, representing the first stage of the dehydrator, was made practically vapor tight. The oil was of 37.55° B. gravity, the average of the better grade of oil in the El Dorado, Kans., field, where these experiments were made. The variations in the temperature of the tests cover average conditions. However, only one season was considered—the summer. In order to get results that would apply for the whole year, two or three additional groups of tests should be run, one in the fall or spring and one in the winter, for the temperatures of the dehydrators are approximately 25° F. higher in winter than in summer. As the temperature of the oil controls the rate of evaporation, it is probable that the loss at such plants during the cooler seasons is fully as large as during summer.

FACTORS CAUSING VARIATION IN PERCENTAGE OF LOSS.

Several factors can cause a variation of the percentage of volume lost. One of these is a change in the quality or quantity of the oil passing through the plant. If the daily production should increase greatly the percentage of volume lost would decrease somewhat, although the actual volume lost would be greater. If a plant were normally dehydrating 300 barrels a day and for some reason this should be increased to 600 barrels a day, then the oil would remain in the plant only half as long. The percentage of loss would be decreased, but would not be one-half of the former rate, for the loss would include a larger volume of very light gasoline which evaporates faster.

If for any reason the kind of oil passing through a plant were changed so that the gravity of the lighter fractions was lowered decidedly, the percentage of loss would be decreased because of the slower rate of evaporation of the heavier fractions.

Figure 11 shows different conditions of operating three plants; 1 and 2 are plants having tanks of the same size and therefore the same area of oil surface exposed, the daily production being considered as a constant. In plant 1, the depths a_1 and b_1 are such that the volume of oil in A_1 and B_1 is twice that in A_2 and B_2, hence the oil has to remain in plant 1 twice as long and the evaporation loss will be almost twice as large.

Now compare plant 1 with plant 3, in the same figure. The area in A_3 and B_3 is double that in A_1 and B_1, respectively, but the depths a_3 and b_3 are such that the volume of oil in plant 3 is exactly the same as that in plant 1. With the same daily production passing through both these plants, the number of hours that the oil is subjected to evaporation in each is the same. As, however, the area exposed is doubled in plant 3, the percentage of volume evaporated is almost double that of plant 1.

Evidently there are many such combinations of daily production, volume of oil held in tanks, relative oil areas exposed, and temperature of dehydrators. For this reason investigation on a scientific basis would necessitate a great number of tests. This one phase alone illustrates the magnitude of the evaporation problem.

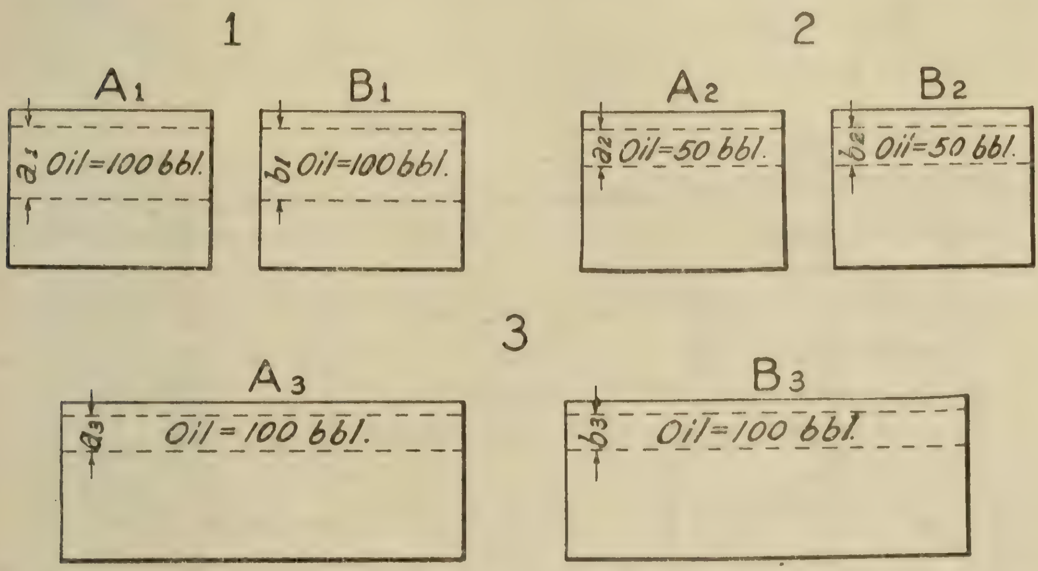


FIGURE 11.—Three dehydration plants handling the same daily production under different conditions; A_1 and B_1=two of A_2 and B_2, respectively. Area of 3=twice the area of either 1 or 2.

Table 7, based on the results of the tests, indicates the volume and the value lost for plants of various sizes obtained from these tests.

TABLE 7.—*Evaporation loss in dehydration plants of different daily capacities and for different temperatures.*

[Gasoline—22 cents per gallon, 42 gallons to the barrel; crude—$3 per barrel.]

Temperature of plant.	Volume lost.	Daily capacity.											
		50 barrels.			100 barrels.			300 barrels.			1,000 barrels.		
		Volume lost.	Value lost.		Volume lost.	Value lost.		Volume lost.	Value lost.		Volume lost.	Value lost.	
			As crude.	As gasoline.		As crude.	As gasoline.		As crude.	As gasoline.		As crude.	As gasoline.
°F.	*Per ct.*	*Gals.*			*Gals.*			*Gals.*			*Gals.*		
84	1. 76	36. 9	$2. 64	$8. 12	73. 9	$5. 30	$16. 26	223	$15. 90	$49. 00	739	$52. 80	$162. 00
105	3. 31	69. 5	4. 97	15. 30	139. 0	9. 95	30. 55	417	29. 80	91. 60	1, 390	99. 40	305. 00
125	5. 46	114. 7	8. 20	25. 25	229. 4	16. 40	50. 40	688	49. 20	151. 40	2, 294	164. 00	503. 00
150	6. 72	141. 2	10. 10	31. 00	282. 3	20. 20	62. 10	847	60. 60	186. 00	2, 823	220. 00	619. 00
200	8. 30	174. 2	12. 45	38. 30	348. 5	24. 90	76. 50	1, 046	74. 60	230. 00	3, 485	249. 00	764. 00

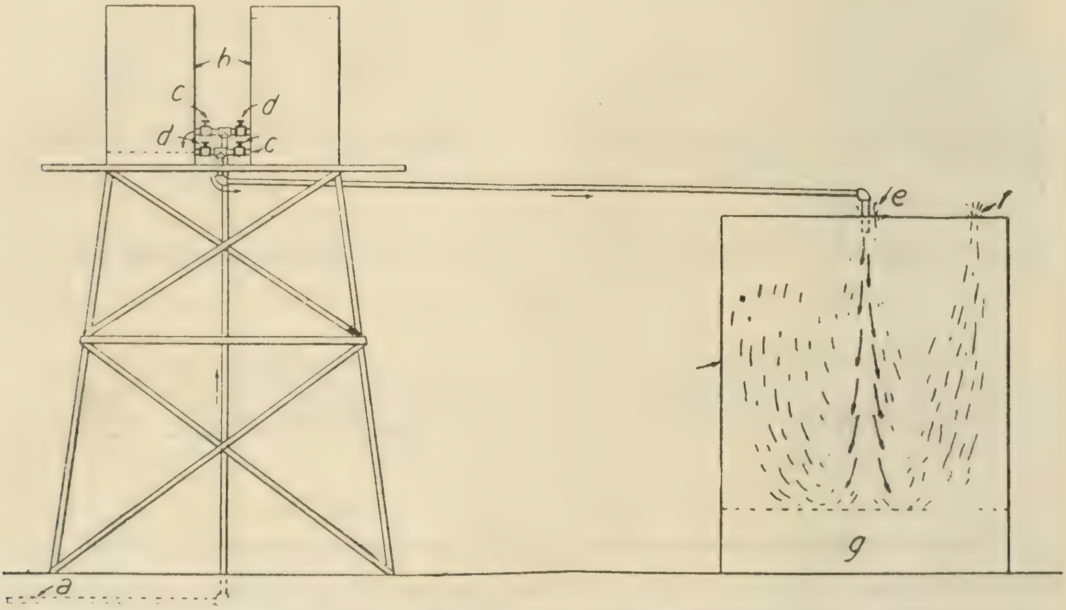


FIGURE 12.—Layout for determining evaporation loss in filling lease tank: *a*, from well; *b*, 25-barrel measuring tanks; *c*, open; *d*, closed; *e*, center hole; *f*, gage hole; *g*, steel tank, unprotected, 500 barrels.

EVAPORATION LOSSES IN FILLING LEASE STORAGE-TANKS.

DESCRIPTION OF LAYOUT.

In order to get some idea of the loss in filling a tank with overhead connections, a test was planned as pictured in figure 12. The oil from the wells was run into the measuring tank *b*, one being filled while the other was emptied. The oil flowed through the pipe to the lease tank *g* at a rate comformable to the production of the wells, in order to duplicate actual conditions. Two tests were made, one with the connecting pipe 30 feet long, the other with the pipe only 11 feet long. The distance from the overshot connections to the surface of the oil was 8 feet in one and 13 feet in the other test. Presentation of the details of these tests is made in Table 8. When oil falls a distance of 12 feet it strikes the surface at a speed of about 28 feet per second, or 19 miles per hour. The resulting splash causes the formation of a spray of oil, and as the oil particles have a large exposed surface compared to their volume, they evaporate very rapidly, filling the tank with rich gasoline vapor. Much of this vapor escapes through openings in the roof of the tank.

TABLE 8.—*Conditions and results of tests on filling lease tanks.*

Description of condition.	Test 1.	Test 2.
Gravity of oil °B..	37	39
Time out of well hours..	10	5
Tanks already passed through	3	1
Length of pipe, measuring tank to stock tank feet..	11	30
Average fall do....	8	13
Daily production barrels..	300	100
Average volume lost per cent..	1.55	2.24

RESULTS OF TESTS.

The results of these experiments show that such filling-tank losses range from 1.5 to 2.25 per cent for one day's production. Naturally, the losses include the evaporation of the oil in the tank and the evaporation of the spray. The results show that the percentage of loss is much less for a 300-barrel than for a 100-barrel output. Producers who allow a very small stream of oil to flow into a comparatively large tank have evidence here that such practice is wasteful. Some leases that produce not over 50 barrels a day have 250-barrel tanks, and as filling one of these at that rate takes about four days, the percentage of oil lost in filling alone can be imagined. The quicker the tank is filled the lower the percentage of loss from this source.

Figure 13 shows the conditions under which test 2 was run. The results of test 1 bring out the fact that with larger production the percentage of loss did not vary greatly when the temperature of the entering oil decreased from about 89 to 82° F. Test 2, illustrated in Figure 13, shows that as the temperature of the entering oil decreased from 86 to 57° F. the rate of loss decreased decidedly. The daily production of the plant used in this test was low, being only 100 barrels.

When the percentage of volume loss was lower, as in test 1, the gravity of the oil was heavier, the number of hours the oil had been out of the well was greater, the number of tanks through which the oil had passed was greater, the length of the pipe line from the measuring tank to the lease tank was less, the average fall was less, and the daily production was three times as great. Every one of these different conditions tends to make the percentage loss in test 1 less than in test 2.

CONCLUSIONS FROM FILLING-TANK TESTS.

Oil should be taken into the bottom of the tank to avoid the splashing and spraying of overshot filling. When a lease has a very low production the tanks used should be small.

Although the percentage of volume lost in these two tests differ widely, still when the relative conditions are taken into consideration they are in reality a check on each other.

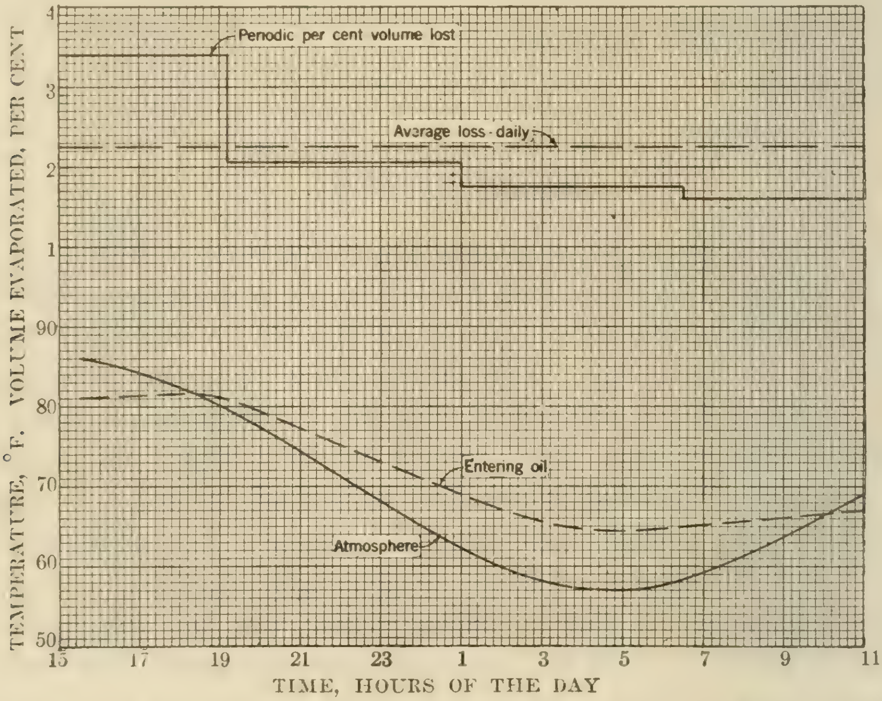


FIGURE 13.—Test 2, temperature conditions and results of test on filling lease tank.

EVAPORATION LOSSES IN STORING OIL ON THE LEASE.

DETERMINATION OF AN AVERAGE TANK.

Data on all the tankage of two of the larger producing companies in the Mid-Continent field were used for deducing the results shown herein. Table 9 shows the number and the total capacity of each size of tanks on leases and the percentage that each size is of the total tankage. The sizes range from 60 to 1,800 barrels.

Table 9.—*Sizes of tanks from which the three principal groups are determined.*

Size of tank.	Number of each size.	Total capacity of each size.	Per cent of total capacity.	Group.	Per cent of total by groups.
Bbls.		*Bbls.*			
60	10	600	0.15	1	31.79
100	118	11,800	2.93		
250	462	115,500	28.71		
500	258	129,000	32.07	2	33.46
800	7	5,600	1.39		
1,000	24	24,000	5.96	3	34.75
1,600	76	114,000	28.34		
1,800	1	1,800	0.45		
	956	402,300	100.00	....	100.00

On examination it is found that the 60-barrel, 100-barrel, 800-barrel, 1,000-barrel, and 1,800-barrel sizes number less than one-sixth of the total, and that their total capacity is less than one-seventh of the total. When reduced to percentage of total capacity, the predominating sizes are shown to be 250-barrel, 500-barrel, and 1,600-barrel tanks. As a result of such observations all sizes of tanks have been grouped in three principal classes. The 250-barrel group includes the 60-barrel and the 100-barrel sizes; the 500-barrel group, the 800-barrel size; and the 1,600 barrel group, the 1,000 and 1,800 barrel sizes. Each of these groups represents about one-third of the total tankage in the Mid-Continent field. From the percentage of volume lost, presented for these three groups, is determined the percentage of volume lost for the average size tank by prorating the loss for each size according to the percentage for each group according to total tankage. To obtain the volume lost and hence the actual value lost, the average sized tank has been considered to hold 750 barrels, which is an approximate average of the three principal sizes.

DESCRIPTION OF TYPES OF TANKS.

Lease tanks are made of wood or of steel. Nearly all the wooden tanks are housed as in figure 14 and in Plate V, *A*, which shows the 1,600-barrel size. The primary reason for putting up this board house is to keep the sun from drying out the staves so much when the tank is empty that it will leak profusely when it is filled. The housing reduces the temperature of the air and vapor above the oil in the tank and decreases the circulation of air due to wind. Wooden tanks have given much trouble from leaks, however, and are being discarded for the bolted steel type as rapidly as possible.

Steel tanks on the lease are usually of the bolted type and only exceptionally are they protected from sun, wind, or rain. Plate

V, *B* and *C*, shows a battery of steel lease-tanks with typical roofs. The roofs, of thin sheet metal, have a 20-inch hole at the center and gage holes at the side. The center holes have lids which are supposed to be kept in place, but generally they are laid about halfway across, this being necessitated by pipes running across the center of the tank. In addition, it may be that three or four smaller holes are cut in the top of the tank for gaging, and these holes are never covered. Plate VI, *A* and *B*, shows large steel lease-tanks with overshot connections and roofs in bad condition.

SPECIAL TYPES OF TANKS.

In addition to these usual types of storage, here and there are others, such as steel tanks, housed with a structure like that for wooden tanks, as shown in figure 21; and steel tanks with a tight jacket, so constructed as practically to prevent the wind causing air circulation. These types represent the most advanced equipment for reducing evaporation. The second type cited is a sample of tank protection designed to keep the oil warmer in winter; it decreases evaporation decidedly. The effect of such housing and the jacketing of steel tanks will be discussed later on page 60. Plate VII, *A*, *B*, and *C*, gives several views of these tanks.

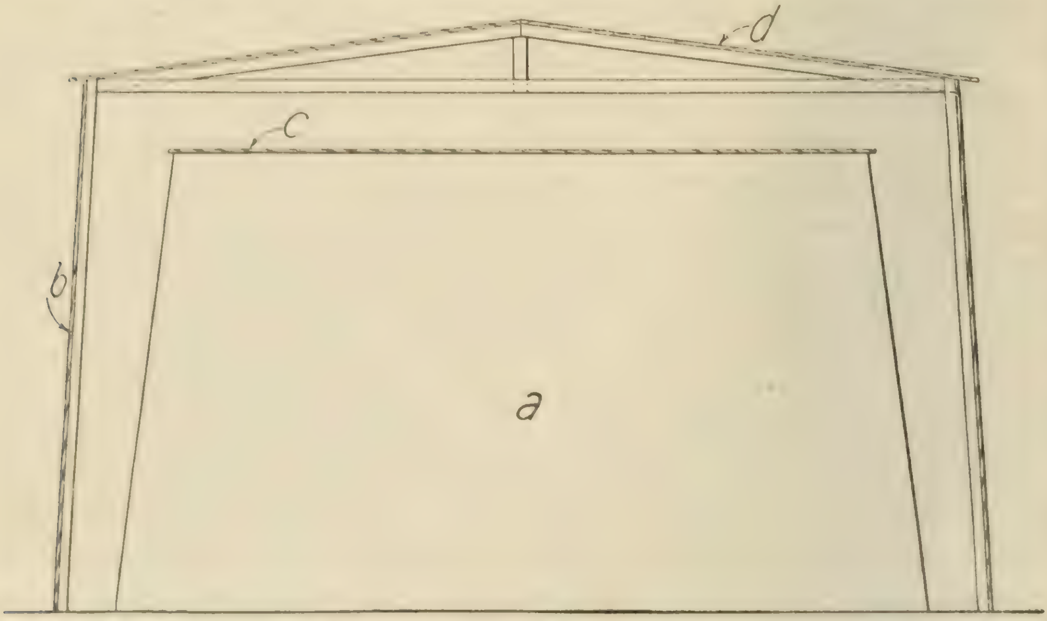
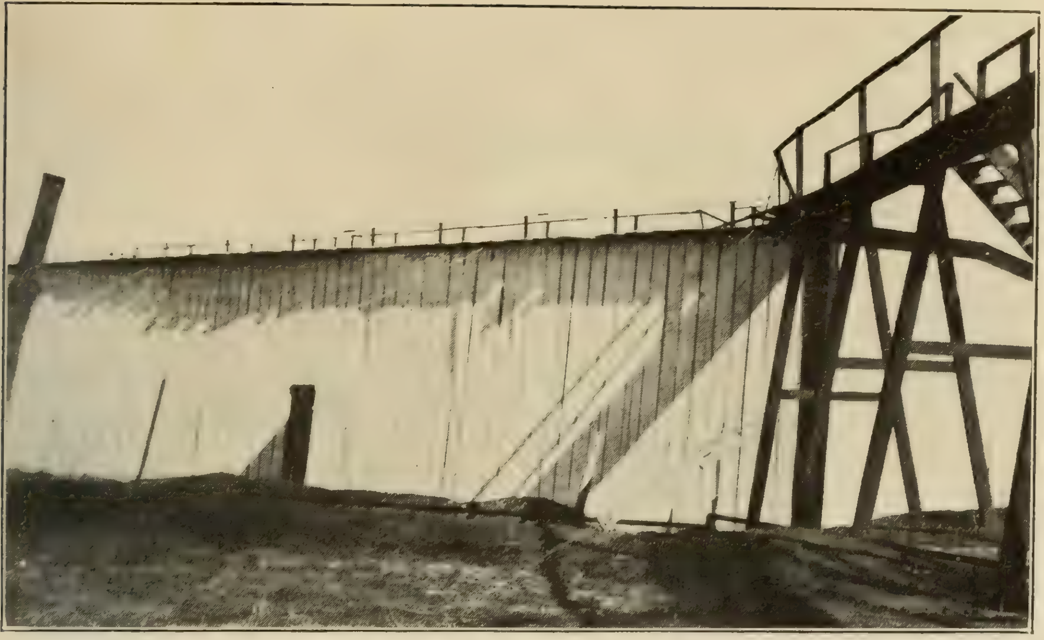
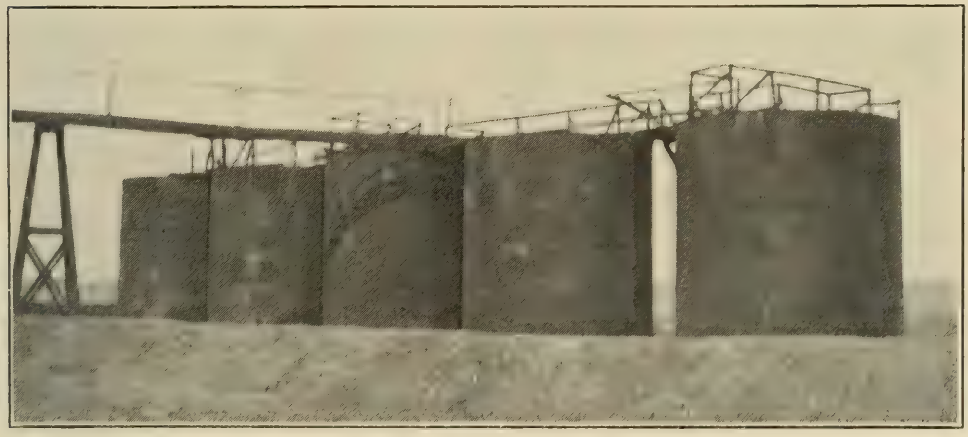


FIGURE 14.—Wood housing for 1,600-barrel lease stock-tank to decrease the circulation of air: *a*, 1,600-barrel wood-stave stock tank; *b*, 1-inch board; *c*, 1-inch boards laid across top of tanks; *d*, 1-inch board roof.

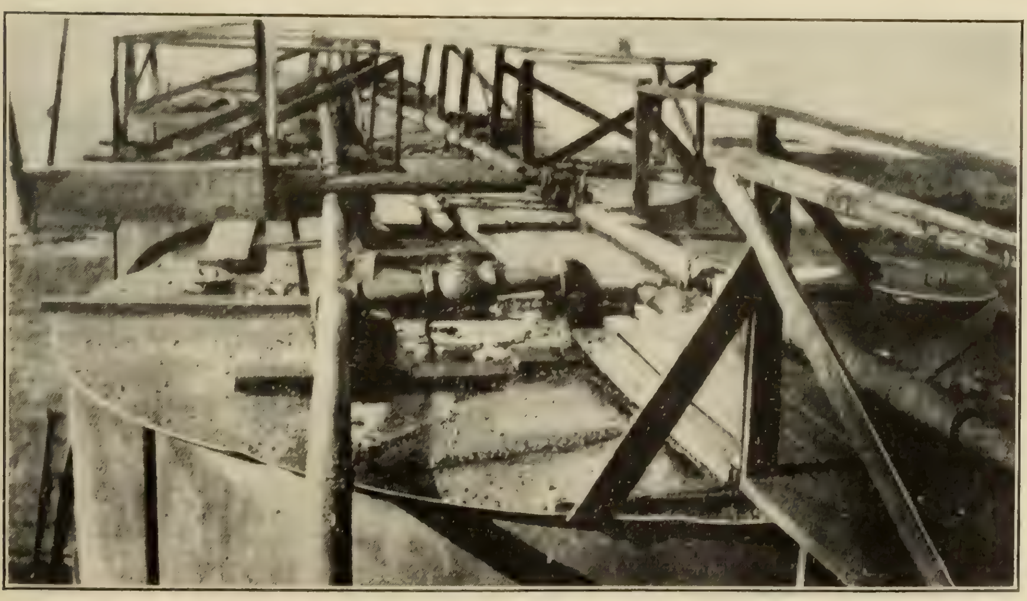
Figure 15 is a detailed sketch of the construction of one of these jackets on a 500-barrel steel tank. The sides are of 2-inch lumber, tongue-and-grooved, held in place by four circular ¾-inch rods. The roof is of 1-inch planks covered with tar paper, battened down in such



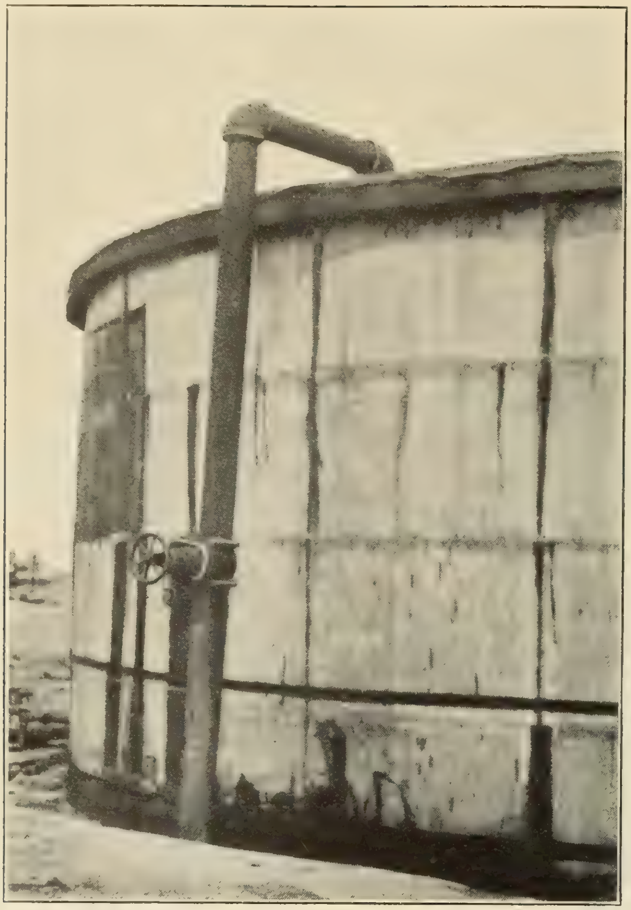
A. HOUSING FOR WOODEN LEASE TANKS.



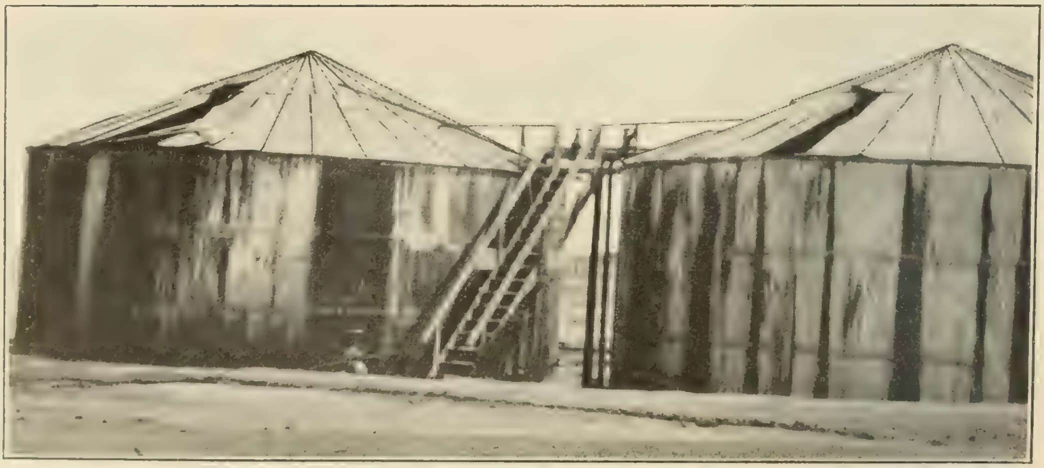
B. BATTERY OF 500-BARREL UNPROTECTED STEEL TANKS.



C. TYPICAL CONDITION OF THE ROOFS OF SUCH TANKS AS ARE SHOWN IN PLATE V, *B*.



A, OVERSHOT CONNECTION FOR LARGE LEASE TANK.



B, LARGE STEEL TANKS WITH BAD ROOF SHOWING NEGLECT OF EVAPORATION LOSSES.

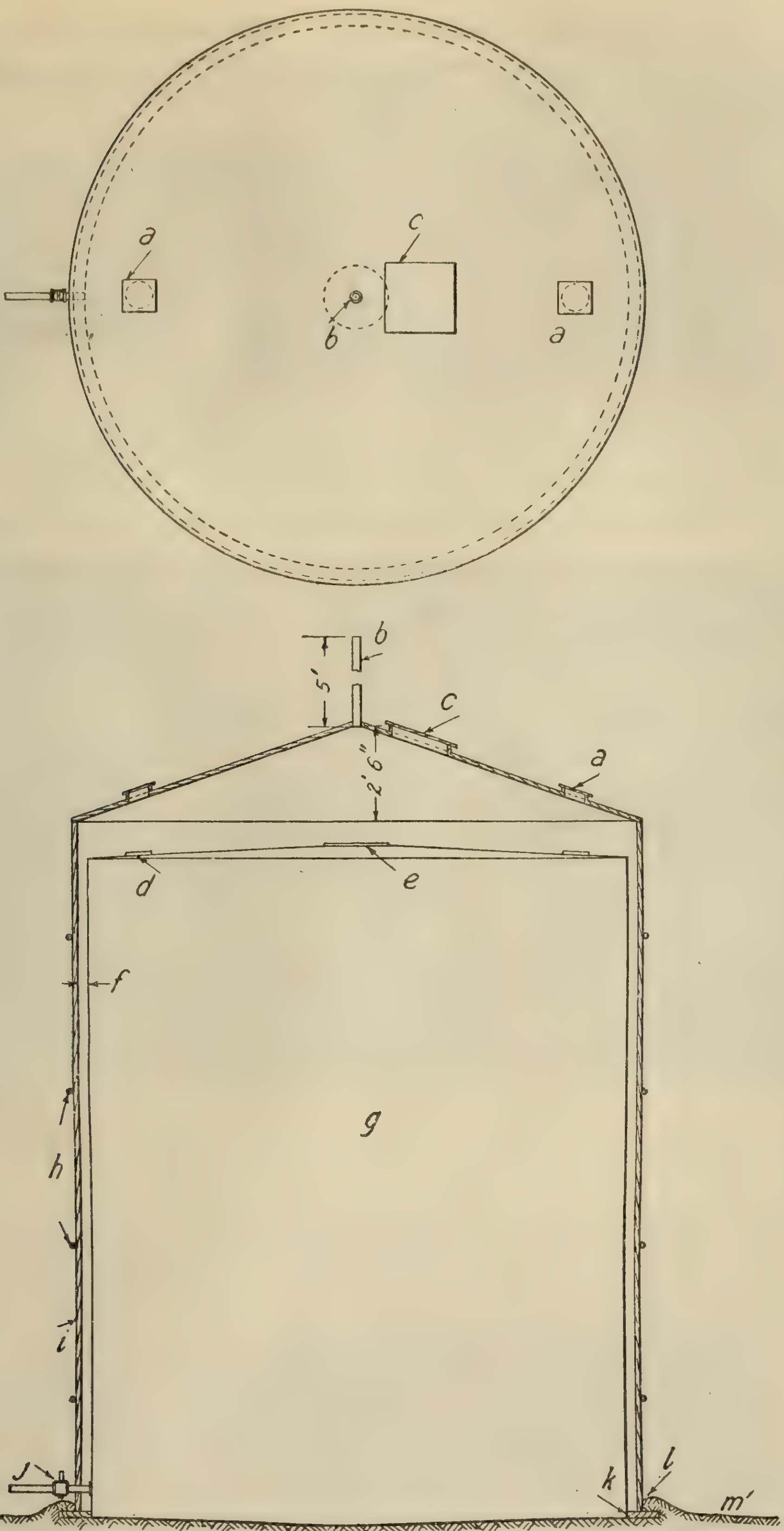


FIGURE 15.—Sketch showing practically air-tight jacket around steel lease tank: *a*, removable cover over 8-inch opening; *b*, 2-inch vent pipe; *c*, removable cover over 20-inch opening; *d*, 8-inch opening; *e*, 20-inch opening; *f*, 3-inch clearance; *g*, tank; *h*, ¾-inch rods; *i*, jacket; *j*, 2-inch stop valve; *k*, 2 by 10 inch pine board base for jacket; *l*, earth seal; *m*, ground line.

a way as to prevent the escape of air. The bottom has for a foundation 2 by 10 inch pine boards sunk slightly into the ground and making an earthen seal to eliminate air circulation.

AVERAGE PERIOD OF STORAGE ON THE LEASE.

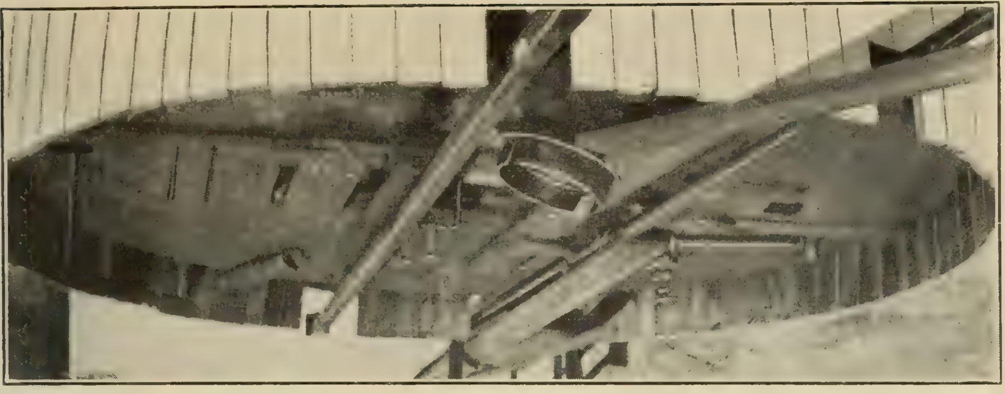
Data from the same companies gives the information shown in Table 10. This table shows that in winter the period of storage is about 70 per cent longer than in summer, a fact well known by oil operators. The average period of storage throughout the year is 5.5 days. This does not include the length of time that the oil previously remained in a flow tank or in a dehydration plant, which may range from a few hours to a whole day. Five days have been taken as the average duration of storage on the lease in all calculations to determine the evaporation loss in the Mid-Continent field.

TABLE 10.—*Number of days that oil is held on the lease throughout the year.*

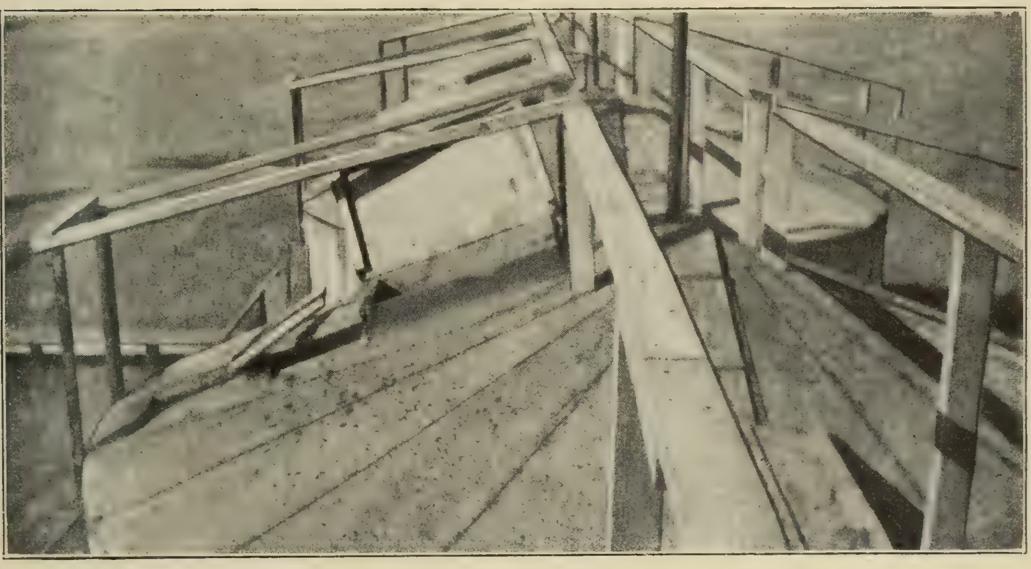
	Days.		Days.
January	7.4	August	4.4
February	7.4	September	5.0
March	7.1	October	4.8
April	5.3	November	5.0
May	4.8	December	6.0
June	4.4		
July	4.4	Average	5.5

SEASONAL TEMPERATURES IN THE MID-CONTINENT FIELD.

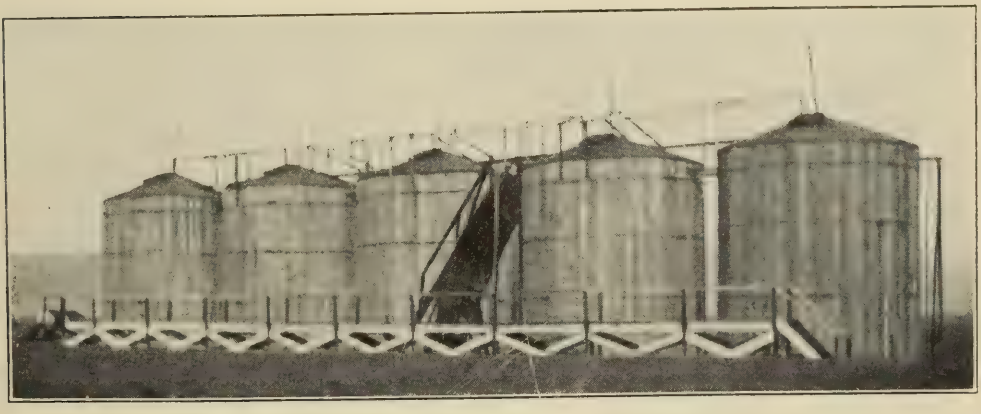
In the Mid-Continent field the yearly cycle of temperature resolves itself naturally into three principal divisions, which do not coincide exactly with the calendar seasons of spring, summer, autumn, and winter, but overlap in places. The results presented here are taken as the average cycle for a period of approximately 30 years and are based on records of the Weather Bureau. As the Mid-Continent field extends from north central Kansas to northern Texas, the temperature of the average normal season for the entire field was determined from temperature records at three places widely separated—Wichita, Kans.; Oklahoma City, Okla.; and Abilene, Tex. In figure 16 the normal temperatures of these places are plotted according to months. As would be expected, the average temperature is cooler farther north, and the differences between the three places are less in summer than in winter. December, January, and February are the coldest months; March, April, May, October, and November are months of medium temperature; June, July, August, and September are the warmest months. The whole year was divided into three



A, TOP OF JACKETED TANK BEFORE CONSTRUCTION OF ROOF.



B. ROOF OF JACKETED TANK SHOWING DOOR OPEN.



C, BATTERY OF JACKETED STEEL LEASE-TANKS.

periods representing these three groups of months, from which the average temperature for each period was determined, as shown in the figure.

CHANGE IN RATE OF EVAPORATION WITH CHANGE OF TEMPERATURE.

After the average seasonal temperature of the oil while on the lease has been determined, it is necessary to determine how the rate of evaporation for an average tank changes with the change in temperature. Figures 17 and 18 show the method. The percentage of volume lost is plotted against the average temperature to which the oil is subjected during a test. In the tests made for this report enough points were not always obtainable to project the curve to average winter temperature. In order to determine the shape of the curve representing this percentage of volume lost, special data were taken which showed a variation in temperature from 81° to 20° F. In these special data all of the evaporative conditions were constant except temperature. When the general shape of this curve had been determined similar data were plotted for the three main groups of lease-storage tanks—250-barrel unprotected steel, 500-barrel unprotected steel, and 1,600-barrel housed wood. Each curve plotted represents the variation in percentage of volume lost for a different

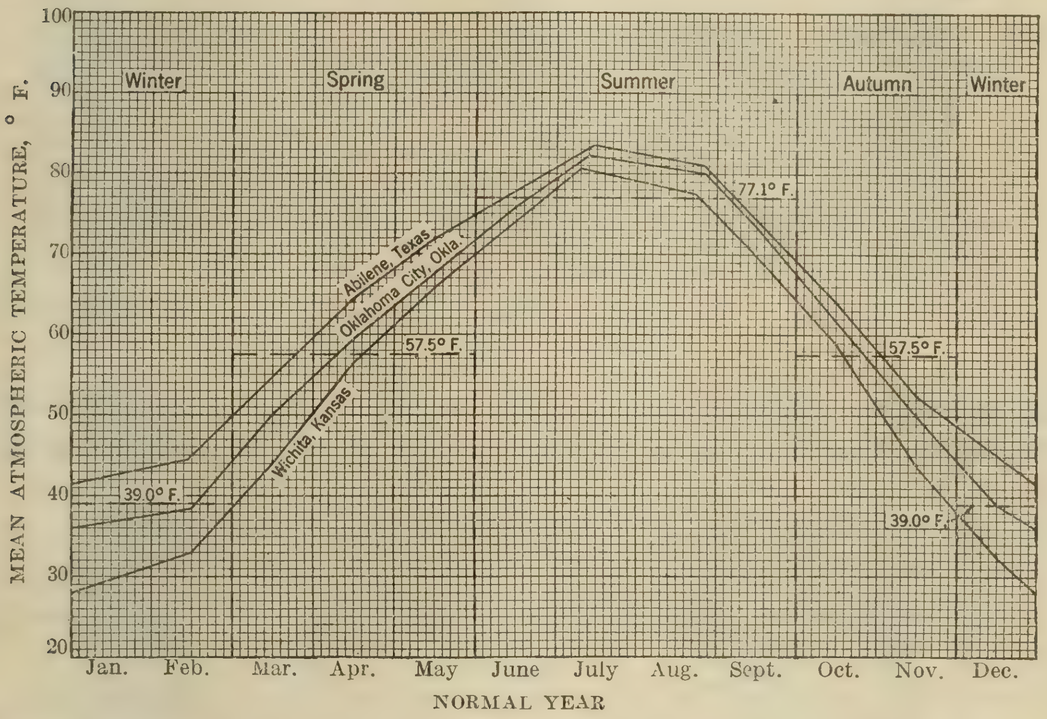


FIGURE 16.—Method of obtaining average normal temperatures for the four seasons of the year in the Mid-Continent field.

period of storage. Table 15 (see p. 68) shows one interpretation calculated from these curves. Many other interpretations can be made by application of local temperature conditions. The curves in these two figures summarize the intensive study of all the tests made on lease storage under different temperature conditions. The average time of storage on the lease (five days), the three general groups of

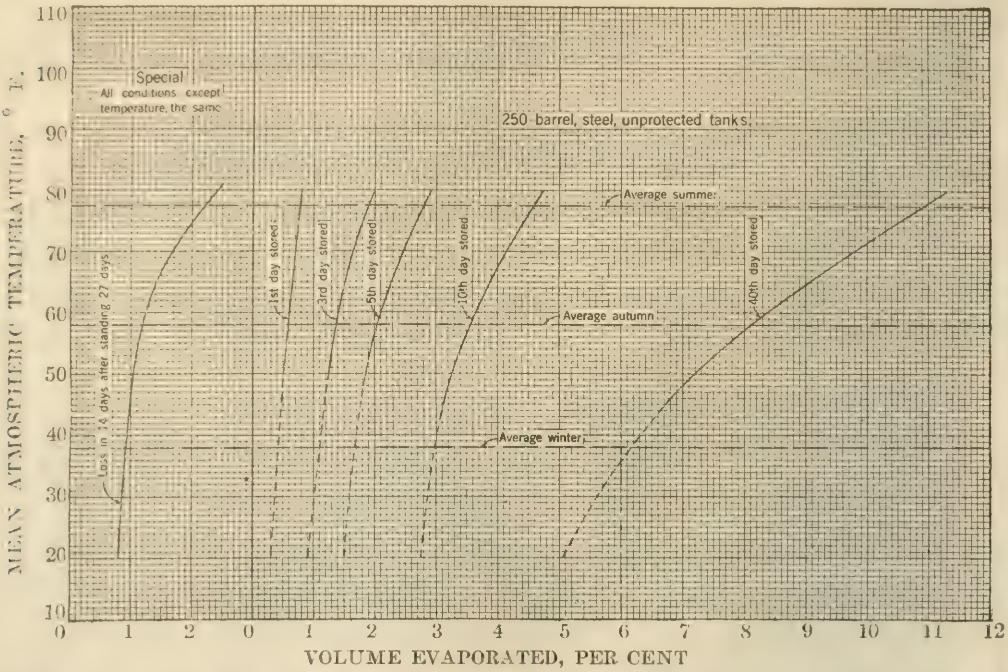


FIGURE 17.—Variation of percentage of volume lost from 250-barrel unprotected steel tanks with variation of mean oil temperature.

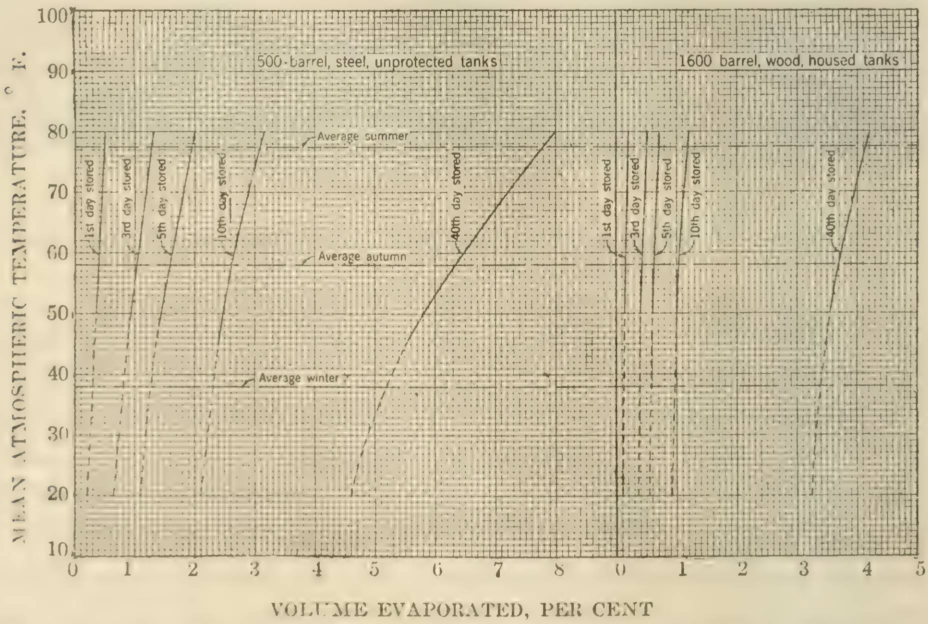


FIGURE 18.—Variation of percentage of volume lost from 500-barrel unprotected steel tanks and 1,600-barrel housed wood tanks with variation of mean oil temperature.

tanks, and the determination of what is considered an average tank have been discussed on preceding pages.

METHOD OF RUNNING A TEST.

Table 1 (see p. 14) gives the data kept on a lease-storage test. As soon as possible after the tank had been filled the first data were taken, including the date and hour of filling the tank, its depth and temperature, and the date and hour that the readings were taken. All tank connections were carefully examined to see that no oil was leaking into or out of the tank. Similar inspection was made each time that the volumetric readings were taken, that is, daily for five days following the initial readings and thereafter at intervals of 10 days until 40 or 45 days had elapsed. At each taking of volumetric readings a 2-quart sample of the oil in the tank was taken in the manner described previously.

DESCRIPTION OF TESTS.

Table 11 shows the general scope of the tests under this heading. An examination of it will give the types of storage that have been covered.

CLASSIFICATION.

Tests were made with 40 tanks. More than one test of the same class was made, and the results shown are consequently a composite of all the tests in that class. In determining the class in which any test belonged, the size and the type of the tank, whether it was protected or not, the season of the year, and the degrees Baumé and source of the oil were taken into consideration. With the exception of the degrees Baumé of the oil, these all had to be exactly the same. In classifying oil by gravity some leeway was allowed. For instance, an oil of 36° B. would be in the same class as oil of 38° B.

TABLE 11.—*Scope of lease-storage experiments covering 40 field tests.*

Tanks used.			Seasons.	Length of experiments.	Oil used.	
Size.	Material.	Protection.			Range.	Source.
Bbl.				*Days.*	° *B.*	
250	Steel	Housed	Summer	10	46	Oklahoma, Kansas.
250	do	None	Summer, autumn, winter	45	34-37	Do.
500	do	Jacketed	do	45	34-37	Do.
500	do	None	do	45	34-37	Do.
1,600	Wood	Housed	do	45	35	Do.

PERCENTAGE OF VOLUME AND ACTUAL VOLUME LOST.

For presenting the percentage of volume and the actual volume lost a number of comparisons have been made, as shown in Table 12, where, for the convenience of the reader, the points of difference are italicized. The results are shown in the form of curves.

A discussion of the different ways in which the losses are presented appear on page 27. The curves for each class will be discussed in detail. To present the results in the four ways noted (actual volume lost, percentage of volume lost, actual value lost, and percentage of value lost) for all nine classes would necessitate a large number of nearly similar curves. Therefore, for each class only the percentage of volume lost and the actual volume lost, in barrels, are given. In covering the actual value and percentage of value lost fewer comparisons have been made.

TABLE 12.—*Classification for comparing percentage of volume and actual volume lost.*

[Items italicized are the variables.]

Illustrative figure.	Designation of comparison.	Tank.			Season.	Tank.			Season.	Tank.			Season.
		Size.	Kind.	Protection.		Size.	Kind.	Protection.		Size.	Kind.	Protection.	
		Bbls.				*Bbls.*				*Bbls.*			
20	*A*	250	Steel	None	*Summer*	250	Steel	None	*Fall*	250	Steel	None	*Winter.*
21	*B*	500	Steel	None	*Summer*	500	Steel	None	*Fall*	500	Steel	None	*Winter.*
22	*C*	500	Steel	Jacket	*Summer*	500	Steel	Jacket	*Fall*	500	Steel	Jacket	*Winter.*
23	*D*	1,600	Wood	Housed	*Summer*	1,600	Wood	Housed	*Fall*	1,600	Wood	Housed	*Winter.*
24	*E*	*250*	*Steel*	*None*	Summer	*500*	*Steel*	*None*	Summer	*1,600*	*Wood*	*Housed*	Summer.
25	*F*	500	Steel	*Jacket*	Fall	500	Steel	*None*	Fall				
26	*G*	500	Steel	*Jacket*	Winter	500	Steel	*None*	Winter				
27	*H*	*500*	*Steel*	*Jacket*	Fall	*1,600*	*Wood*	*Housed*	Fall				
28	*I*	250	Steel	*Housed*	Summer	250	Steel	*None*	Summer				

As summer gradually becomes autumn, and autumn gradually becomes winter, it is impossible to get a period of 30 or 40 days that represents exactly any single season. Figure 19 shows the average oil temperature of the tests covering classes *A*, *B*, and *C*.

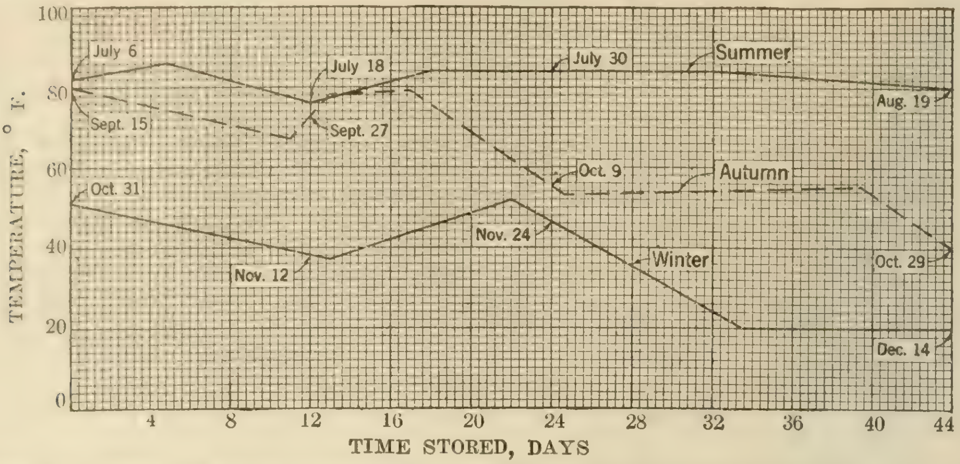


FIGURE 19.—Mean oil temperatures at which lease-storage tests were run for summer, autumn, and winter, applying to figures 20 to 22.

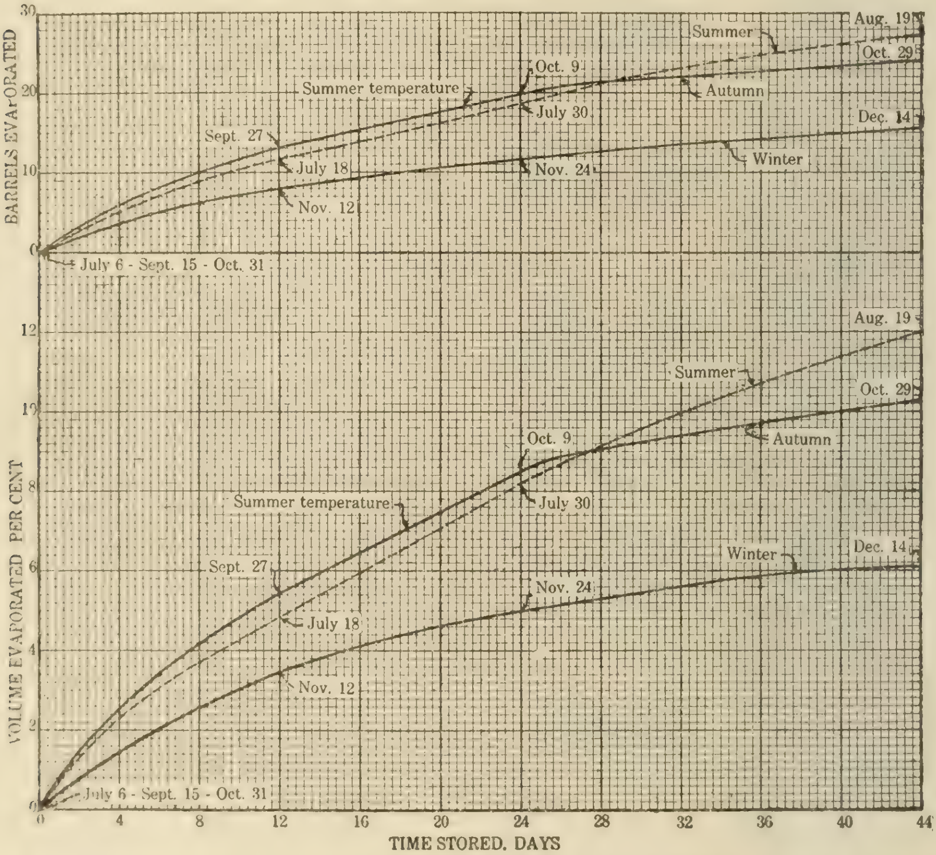


FIGURE 20.—Comparison *A*. Barrels evaporated and percentage of volume evaporated from 250-barrel unprotected steel lease-tanks during summer, autumn, and winter. "Summer temperature" is indicated on the "autumn" curve, because the evaporation during the last part of September was greater than for the first few days (see fig. 19).

250-BARREL UNPROTECTED STEEL TANKS—SUMMER, AUTUMN, AND WINTER.

Figure 20 shows the results of tests covering class *A*. Not until October 10 does the lower temperature of autumn begin to affect the rate of evaporation, and though the average temperature about November 10 is 40° F., or very close to the average winter temperature for the Mid-Continent field, the percentage of volume lost is only slightly less than that in July and September when the temperature was about 78° F. The winter test showed a loss of 3.1 per cent after an exposure of 10 days, whereas the two tests during the hot season showed an average loss of 4.5 per cent. This shows that the rate of evaporation does not decrease as rapidly as the decrease in temperature. Another point worthy of note is that from December 4 to December 14, although the temperature averaged 20° F., the oil continued to lose through evaporation. During those 10 days, after having been already exposed for 34 days, the oil lost 2 barrels, or 0.25 per cent, of its original volume.

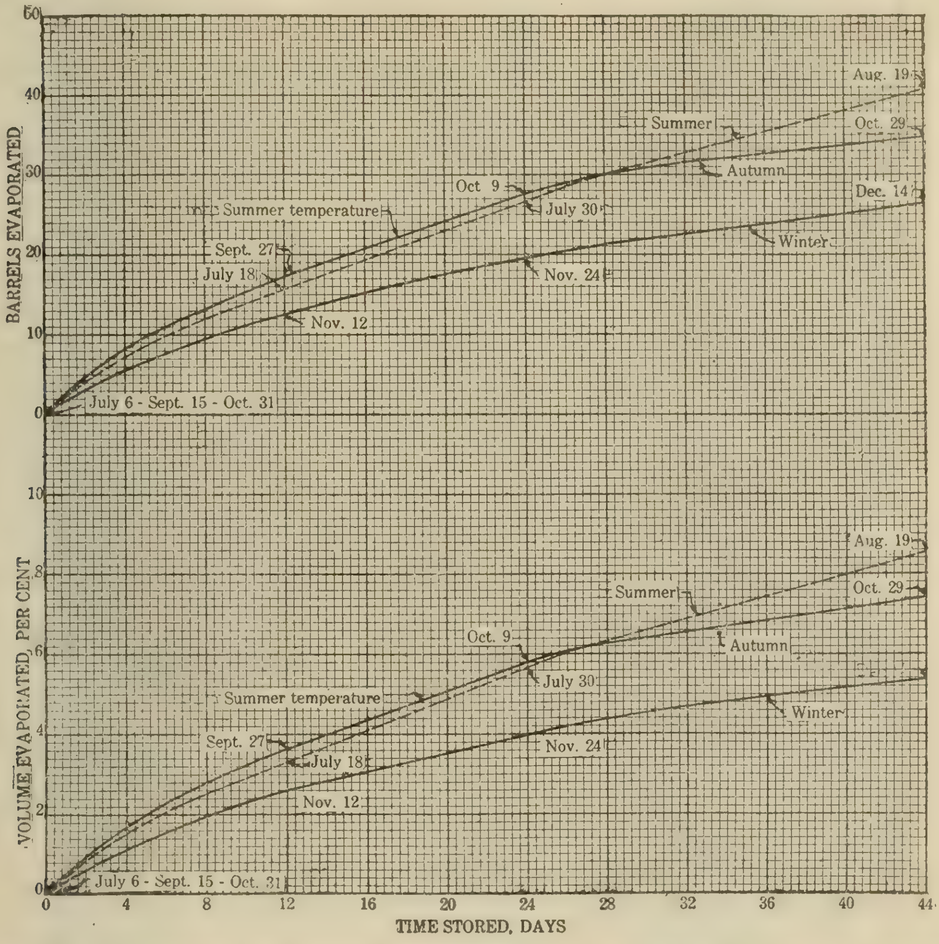


FIGURE 21.—Comparison *B*. Barrels evaporated and percentage of volume evaporated from 500-barrel unprotected steel lease-tanks during summer, autumn, and winter. See note on figure 20 concerning "summer temperature."

500-BARREL UNPROTECTED STEEL TANKS—DIFFERENT SEASONS.

Comparison *B* is shown in Figure 21. These curves give data similar to those for comparison *A*, and the same effects are found from the tests. The two summer curves do not coincide exactly because they are the results of two entirely different tests, but they are close enough to check each other. For the temperatures at which these tests were made, see figure 19.

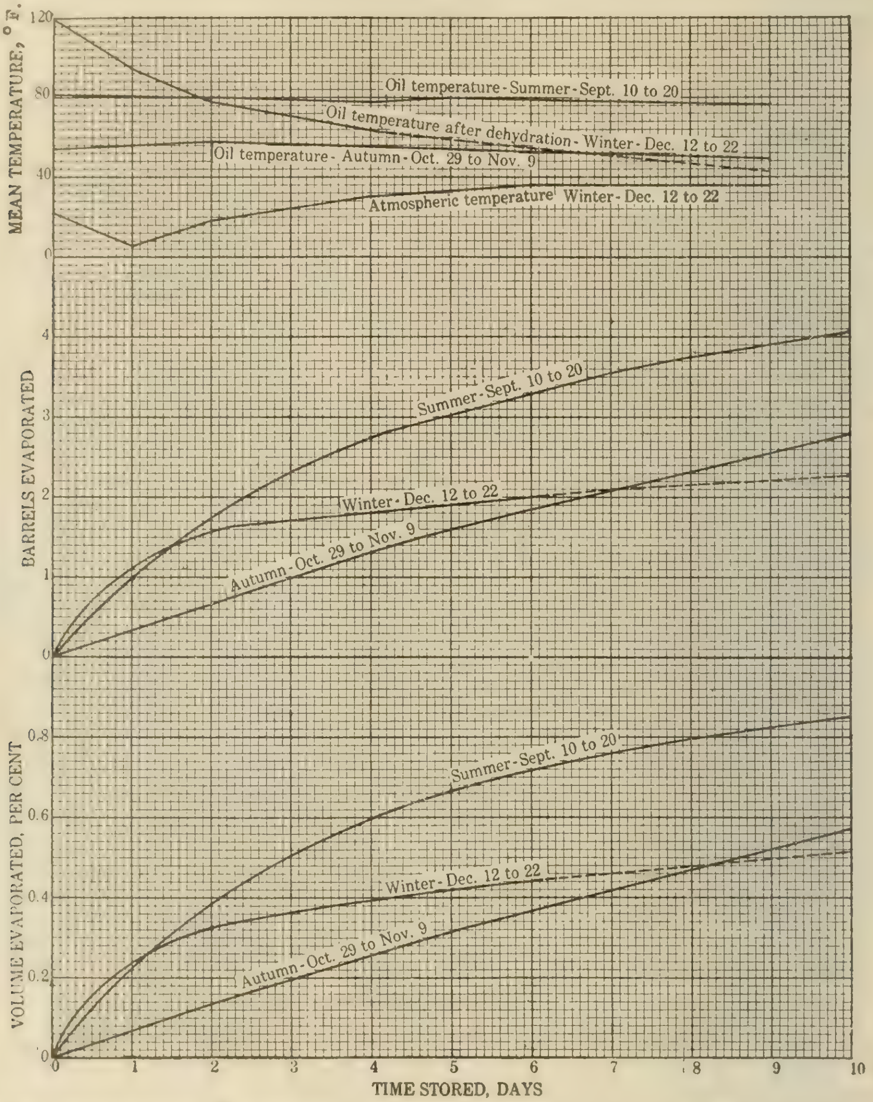


FIGURE 22.—Comparison *C*. Barrels evaporated and percentage of volume evaporated from 500-barrel jacketed steel tanks during summer, autumn, and winter and respective mean temperatures of oil.

500-BARREL JACKETED STEEL TANKS—DIFFERENT SEASONS.

Figure 22 shows comparison *C*—500-barrel jacketed steel tanks in summer, autumn, and winter. The temperatures of the oil for these various tests are shown in figure 19. The loss in autumn was less than for the first six days of winter, because the temperature of the oil at the start of the winter experiment was 120° F., the oil having passed through a dehydration plant in that experiment. The slow approach of the oil temperature and the atmospheric temperature shows the effect of the air-tight jacket about the tank, for the higher temperature of the oil, regardless of the much lower temperature of the atmosphere outside, caused greater evaporation loss than that in the autumn test. As soon as the oil in the winter test had approached the temperature of the autumn test, the rate of evaporation became much slower. The autumn test shows a very slow rate of evaporation, and the curve representing this rate is almost a straight line. In summer, when the rate of evaporation is nearly twice as rapid, the curve flattens as time goes on.

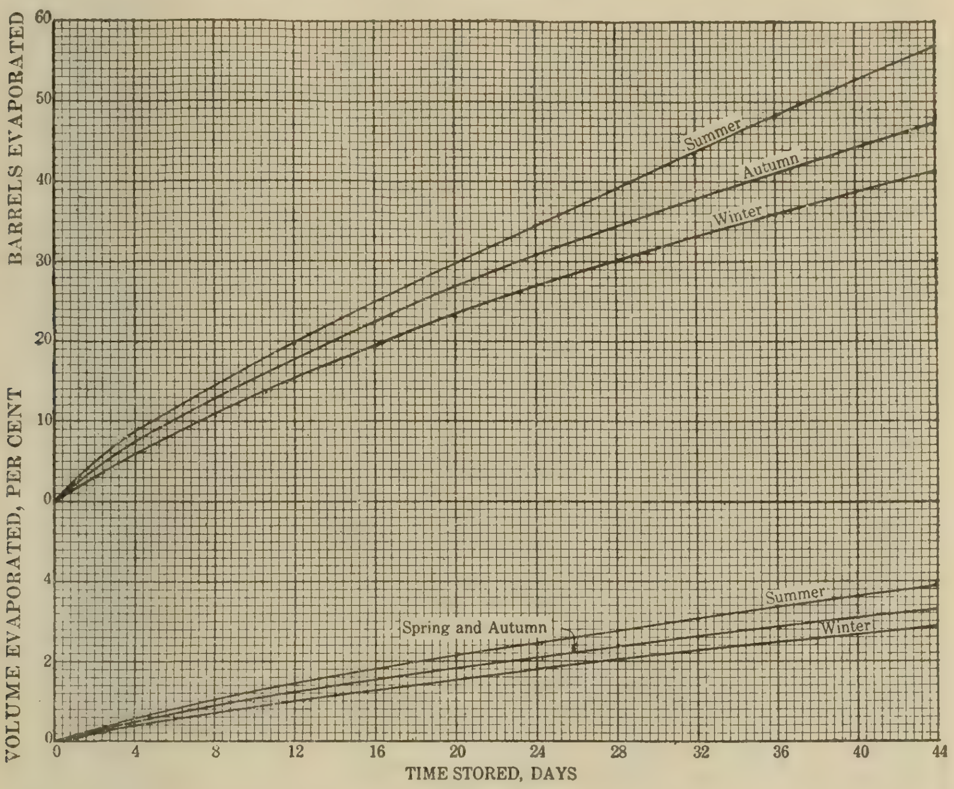


FIGURE 23.—Comparison *D*. Barrels evaporated and percentage of volume evaporated from 1,600-barrel housed wood tanks during summer, autumn, and winter.

A very important point to notice in comparing figure 22 with figure 20 or 21, is this: The percentage of loss in five days in autumn is less than one-half of that in summer for jacketed tanks. In unprotected 500-barrel tanks, the percentage of loss on the fifth day in winter is as much as seven-tenths of that in summer (see fig. 21, p. 55). The conclusion from these observations is that exposure to the wind affects greatly the rate of evaporation loss, regardless of the temperature.

1,600-BARREL HOUSED WOOD TANKS—DIFFERENT SEASONS.

Figure 23 shows the results of the tests noted in comparison *D*. The temperature may be found in figure 19 (see p. 54). The 1,600-

barrel wood tank tested is like that shown by figure 14 (see p. 46). The percentage of loss in this wood tank is decidedly lower than in the steel tank, not because the material is wood, but because the tank is housed and therefore partly protected from air currents.

COMPARISON OF 250 AND 500 BARREL UNPROTECTED STEEL AND 1,600-BARREL HOUSED WOODEN TANKS.

Comparison *E* shows the difference between 250-barrel, 500-barrel unprotected steel, and 1,600 barrel housed wooden tanks for the summer. In figure 24 it is noted that the per cent volume lost from a 1,600-barrel wooden housed tank is only about one-third of that lost from either a 250 or 500 barrel tank. The number of barrels lost for the same period of time, however, is greater for a 1,600-barrel tank. A very important feature of the curves representing the 250 and 500

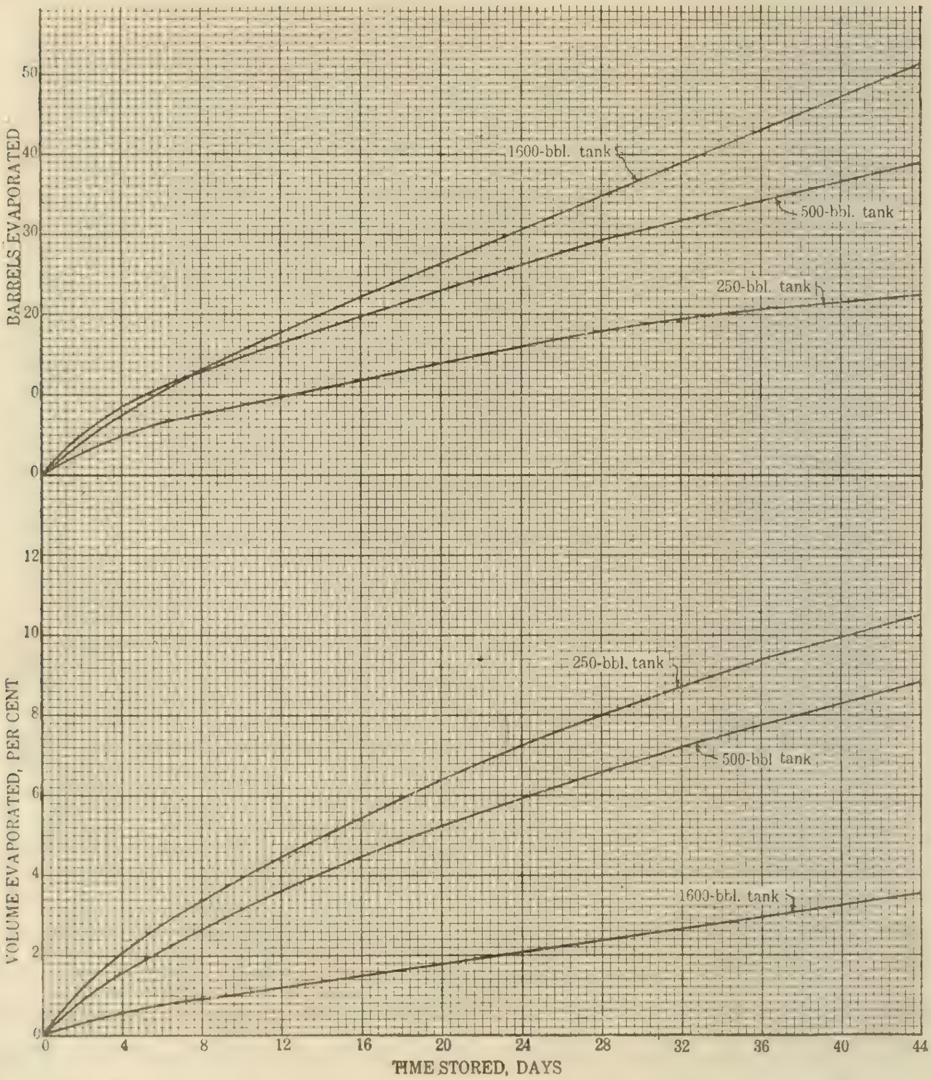


FIGURE 24.—Comparison *E*. Barrels evaporated and percentage of volume evaporated from 250 and 500 barrel unprotected steel tanks and 1,600-barrel housed wood tanks in summer.

barrel tanks is that the per cent volume lost from a 250-barrel tank is not much greater than the per cent volume lost from a 500-barrel tank. This is due to the fact that as compared to a 250-barrel tank a 500-barrel tank of crude oil contains twice as much of the very light products which evaporate at a rapid rate. As soon as the lightest fractions of a 250-barrel tank have evaporated the rate is slowed down. When the same number of barrels have been evaporated from the 500-barrel tank as from the 250-barrel tank there still remains in the 500-barrel tank the same quantity of fractions above the point to which the 250-barrel tank has evaporated.

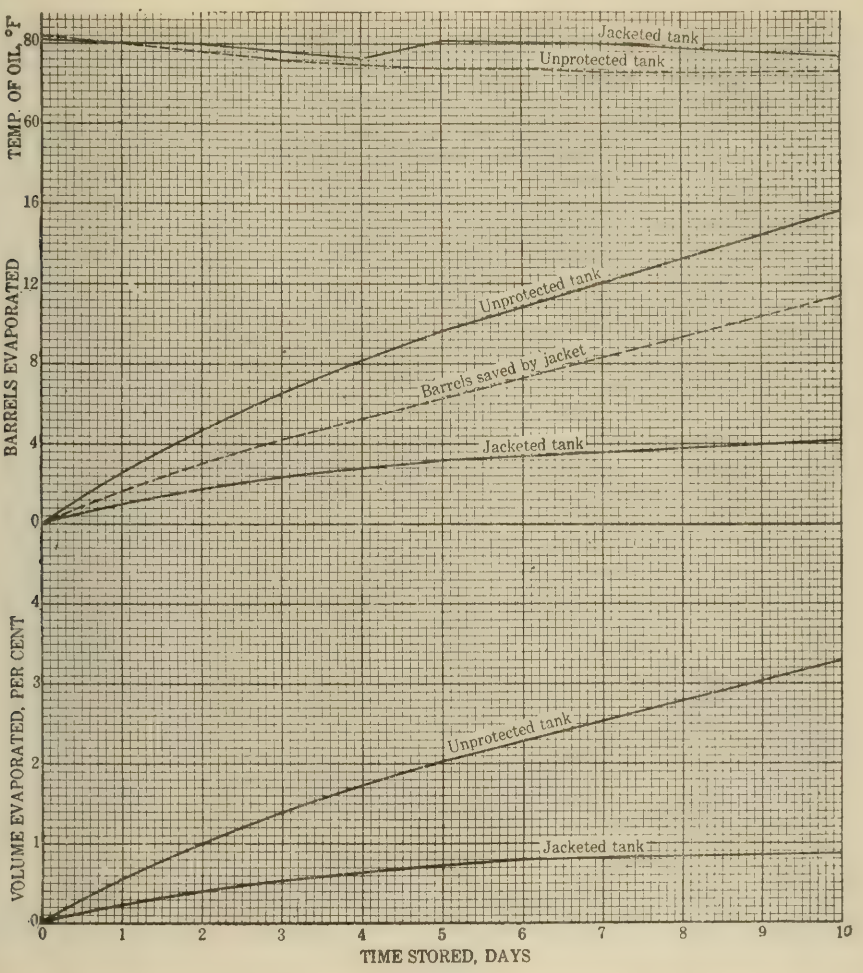


FIGURE 25.—Comparison *F*. Comparison of barrels evaporated and percentage of volume evaporated from 500-barrel unprotected and jacketed steel tanks in autumn.

COMPARISON OF JACKETED AND UNPROTECTED STEEL TANKS.

Comparison *F*, illustrated by figure 25, shows the value of protecting tanks from wind and free circulation of air. The center curve under "barrels evaporated" shows in the dashed line the number of barrels that are saved by the construction of the jacket, amounting to 6.2 barrels of gasoline saved in five days. As crude oil this has a value of $19.20 at $3.00 per barrel.

Comparison *G*, which is shown in figure 26, is similar to comparison *F*, except that the latter is for autumn, whereas the former is for winter. Even when the temperature is very low the jacketed tank still shows a decided saving over the unprotected one, proving clearly that wind and free circulation of air have much more to do with the rate of evaporation of crude oil than temperature. The surface of the oil in a jacketed tank is always still; in one that is unprotected the surface of the oil is constantly rippling.

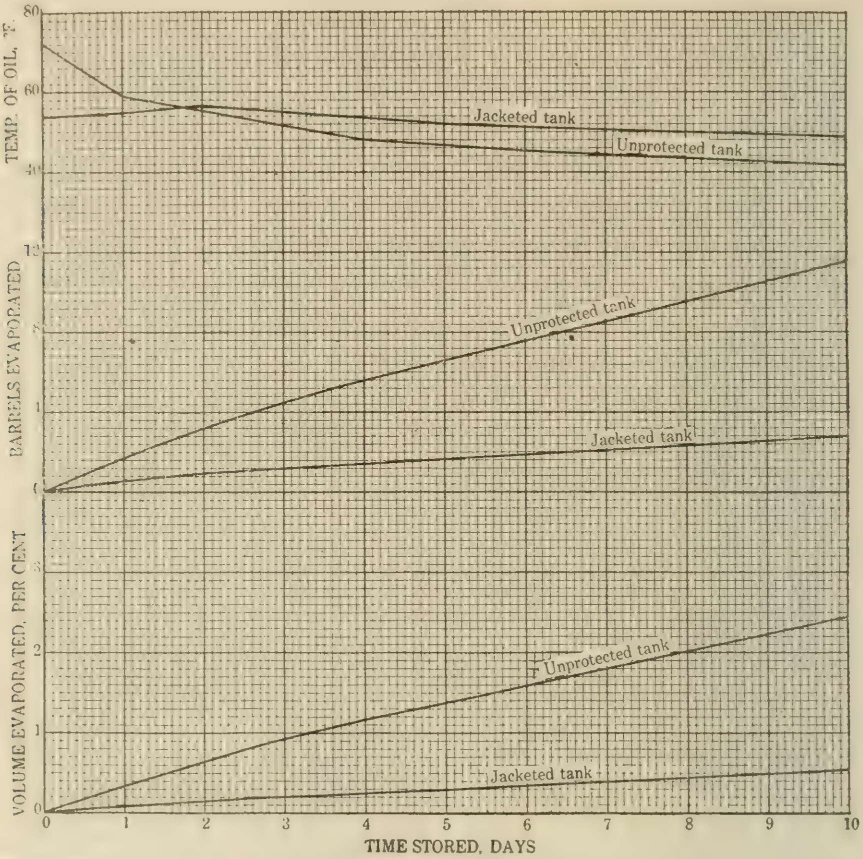


FIGURE 26.—Comparison *G*. Comparison of barrels evaporated and percentage of volume evaporated from 500-barrel unprotected and jacketed steel tanks in winter.

COMPARISON OF JACKETED AND HOUSED TANKS.

In comparison *H* (see fig. 27) the evaporation from a single 500-barrel jacketed steel tank and that from a 1,600-barrel housed wood tank have been compared, both as to per cent volume lost and barrels lost. The number of barrels lost by one 500-barrel jacketed tank has been multiplied by three in order to give a fair comparison to the barrels lost on a 1,600-barrel tank. The three 500-barrel jacket tanks in this case store the same volume as the 1,600-barrel tank, namely, about 1,430 barrels. Moreover, the area exposed in a wooden tank is 151 square feet, whereas in the three 500-barrel tanks the area is 165 square feet. The areas are, therefore, nearly the same. The results, then, should give a satisfactory comparison of jacketed and housed tanks, for the temperatures as shown in figure 25 are almost identical. The loss from tanks of either type seems to be practically the same for the first five days. However, as time lengthens to 44 days, the comparison of volume lost is much less for the jacketed than for the 1,600-barrel tank. By the forty-fourth day the volume lost from three jacketed tanks is 25 barrels. For the 1,600-barrel tank, the loss is 57 barrels, a saving of 32 barrels by the jacket.

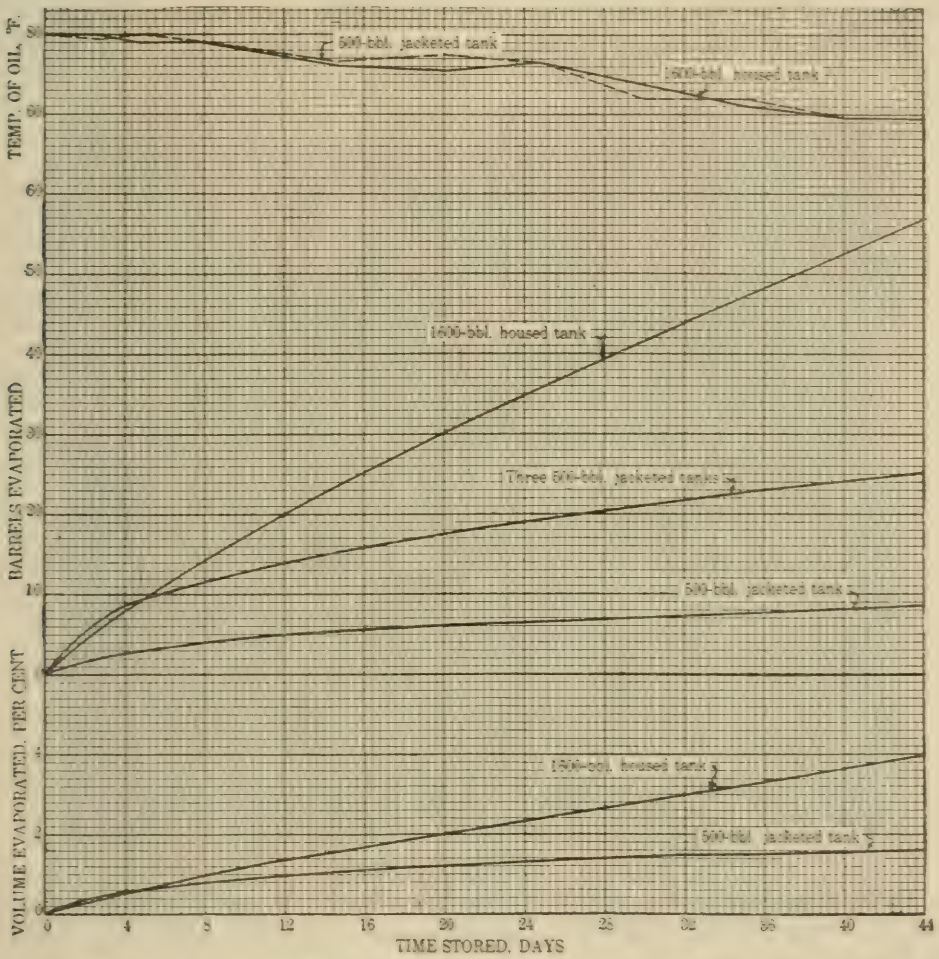


FIGURE 27.—Comparison *H*. Comparison of barrels evaporated and percentage of volume evaporated from 1,600-barrel housed wood tanks and 500-barrel jacketed steel tanks in autumn.

This is additional proof that air circulation is the main factor in evaporation, for the loose housing allows more air circulation than does the jacketed tank, even though both are shaded.

COMPARISON OF HOUSED AND UNPROTECTED STEEL TANKS.

Comparison *I* (see fig. 28) shows evaporation from jacketed and unprotected 250-barrel steel tanks in summer. The only difference between the tanks is that one class has a house similar to the housing of the wooden tank shown in figure 14 (p. 46). The value of such housing is shown when these figures are observed. In 10 days the saving due to the housing has been 7.6 barrels. For further discussion see page 87.

LOSS BY SO-CALLED EMPTY TANKS.

When a lease tank has been emptied by the pipe-line company, approximately 1 foot of oil and B. S. remains in the tank, and is subject to loss by evaporation. Tests were made which show that the percentage of volume lost under such conditions is much higher than for a full tank. In fact, the nearer a tank is to being "empty," the greater will be the percentage of volume lost, though the actual barrels lost are smaller; therefore, a producer will suffer greater proportional loss from a large number of partly full tanks than from a smaller number of full ones.

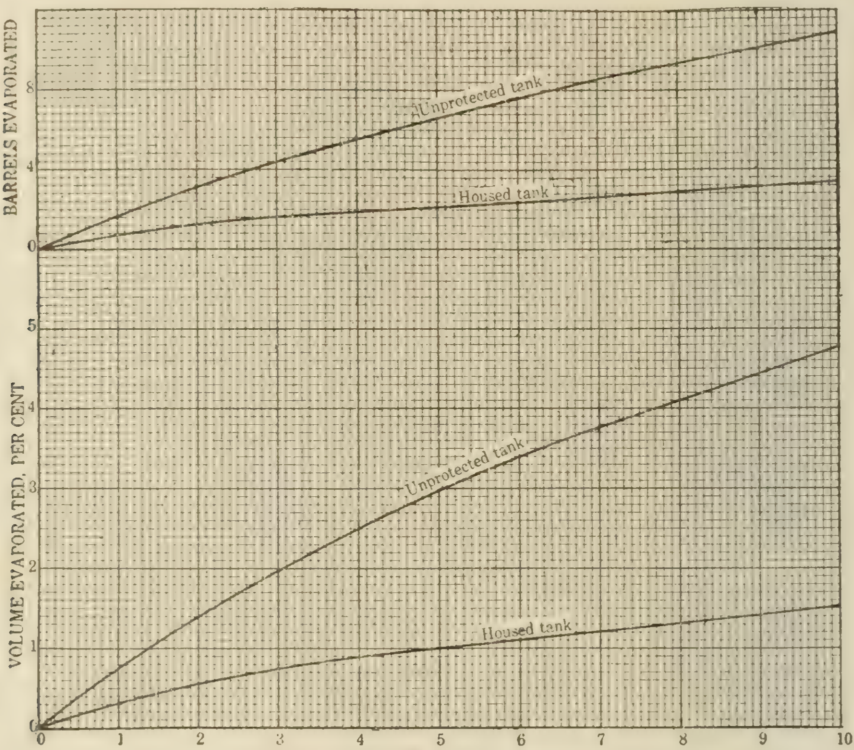


FIGURE 28.—Comparison *I*. Comparison of barrels evaporated and percentage of volume evaporated from 250-barrel housed steel tanks and from 250-barrel unprotected steel tanks during the summer.

ACTUAL VALUE AND PERCENTAGE OF VALUE LOST.

For the sake of simplicity, another set of comparisons has been made to show the actual value and the percentage of value lost. Table 13 gives these comparisons in brief.

250-BARREL UNPROTECTED TANKS.

Figure 29 shows comparison *J*, which is the effect of evaporation on 250-barrel tanks for the average season of the year. As discussed in Part I, the percentage value lost has been calculated as loss as gasoline at 22 cents per gallons versus crude at $3 per barrel, loss as gasoline at 22 cents per gallon versus refined products at $4.28 per barrel, and loss as crude versus crude. These losses are shown in figure 29 by curves 1, 2, and 3. The actual value lost has been shown as crude and as gasoline.

TABLE 13.—*Classification for comparing actual and percentage of value lost.*

Illustrative figure.	Designation of comparison.	Size.	Season.	Loss shown.
		Bbls.		
33	J	250	Average	Actual value and percentage of value.
34	K	500	....do	Do.
35	L	1,600	....do	Do.

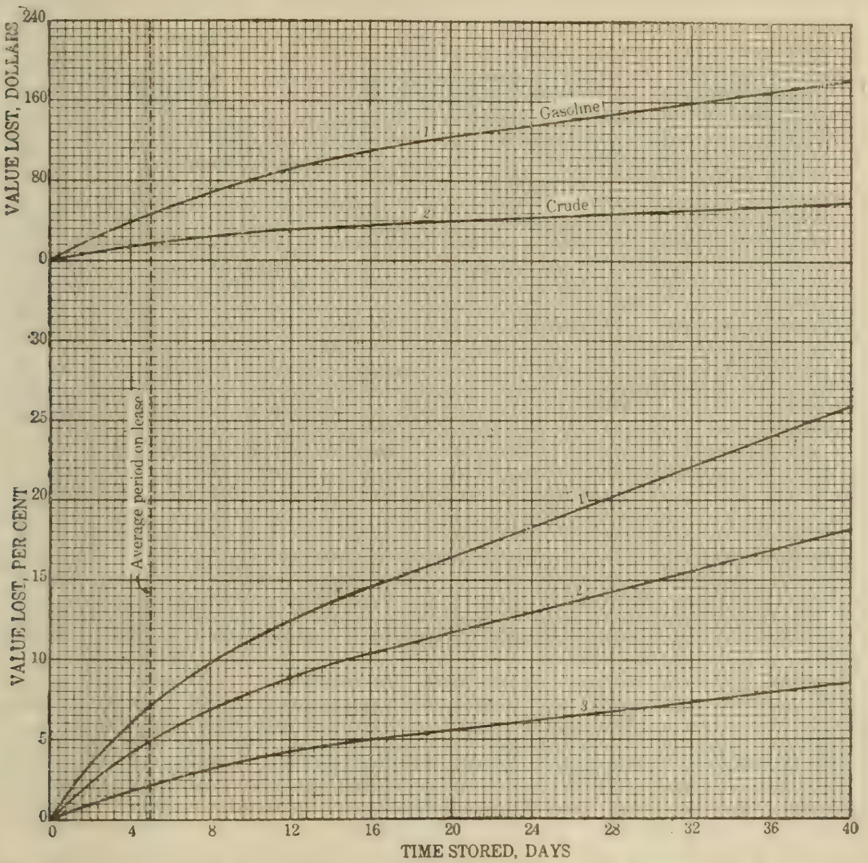


FIGURE 29.—Comparison *J*. Actual value lost by 250-barrel unprotected steel tanks for the average season, considered as loss as gasoline at 22 cents per gallon and loss as crude at $3 per barrel. Percentage of value lost by similar tanks, considered as loss as gasoline at 22 cents per gallon v. crude at $3 per barrel, loss as gasoline at 22 cents per gallon v. refined products at $4.28 per barrel, and loss as crude v. crude.

500-BARREL UNPROTECTED AND 1,600-BARREL HOUSED TANKS.

Figure 30 shows comparison *K*, and figure 31 comparison *L*.

PERCENTAGE OF VALUE AND VOLUME LOST ON THE LEASE IN THE MID-CONTINENT FIELD.

The percentage of value and of volume lost by the average (750-barrel) lease tank for the average season is presented graphically in figure 32. This shows the percentage of value lost for the three bases already described and the percentage of volume lost from an average lease tank by seasons for any period of storage to 40 days in the Mid-Continent field. Data for plotting the percentage of value lost were taken from Table 15 with the application of the percentage of value factors previously described in Part I.

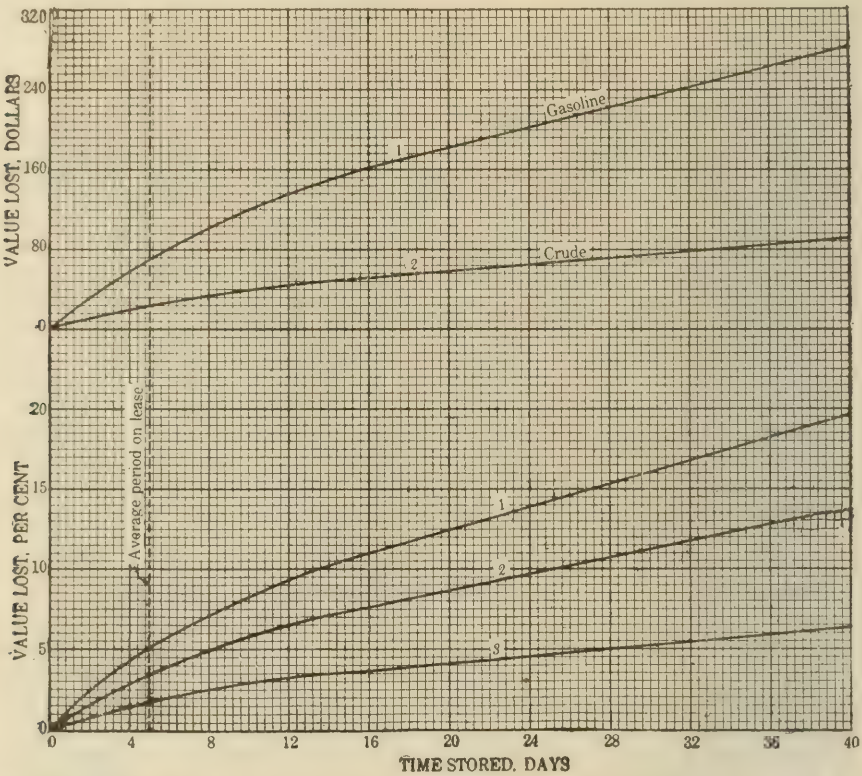


FIGURE 30.—Comparison *K*. Actual loss from 500-barrel unprotected steel tanks for the average season considered as loss as gasoline at 22 cents per gallon and loss as crude at $3 per barrel. Percentage of value lost by similar tanks, considered as loss as gasoline at 22 cents per gallon v. crude at $3 per barrel, loss as gasoline at 22 cents per gallon v. refined products at $4.28 per barrel, and loss as crude v. crude.

In Table 15 (see p. 68) the average for the year for the fifth day of storage (determined as the average period of storage on the lease) is 1.46 per cent, representing the average volume lost by all the oil produced in the Mid-Continent field during storage on the lease alone. This does not include losses in passing through flow tanks and in filling the lease tanks or losses during pipe-line or tank-car distribution. Table 14 has been compiled from this figure for average percentage of volume and from the U. S. Geological Survey data on production in the Mid-Continent field during 1919.

TABLE 14.—*Loss in the Mid-Continent field by five days' storage on the lease, 1919.*

Season.	Mid-Continent production.	Average volume lost.	Actual volume lost.			Value lost.	
						As crude.	As gasoline.
	Barrels.	*Per cent.*	*Barrels.*	*Gallons.*	*Cubic feet.*		
January, February, and December	45,000,000	1.14	513,000	21,540,000	2,880,000	$1,539,000	$4,740,000
March, April, May, October, and November	78,400,000	1.40	1,098,000	46,120,000	6,170,000	3,294,000	10,150,000
June, July, August, and September	72,200,000	1.80	1,298,000	54,520,000	7,290,000	3,894,000	11,990,000
Whole year	195,600,000	....	2,909,000	122,180,000	16,340,000	8,727,000	26,880,000

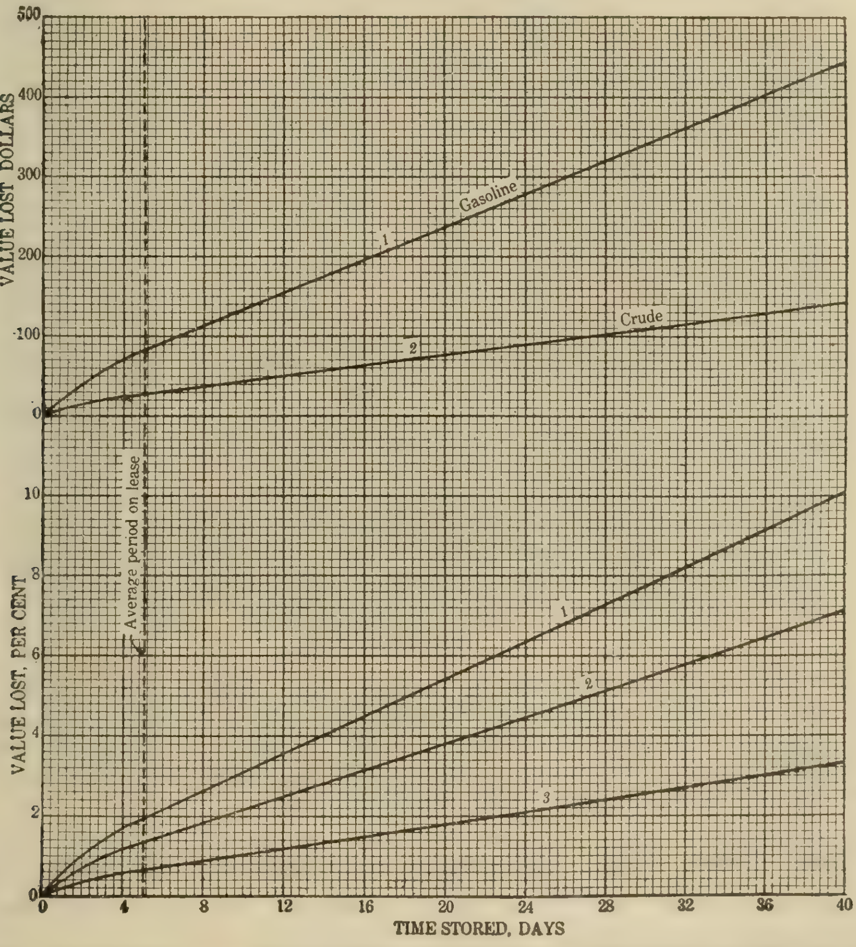


FIGURE 31.—Comparison *L*. Actual value of loss from 1,600-barrel housed wood tanks, including loss as gasoline at 22 cents per gallon and loss as crude at $3 per barrel. Percentage of value lost by similar tanks, including loss as gasoline at 22 cents per gallon v. crude at $3 per barrel, loss as gasoline at 22 cents per gallon v. refined products at $4.28 per barrel, and loss as crude v. crude.

As the volume thus lost is gasoline, it is given the value of that commodity, assumed to be 22 cents per gallon. This shows that, from a production of 195,600,000 barrels in 1919 the actual volume lost was 2,909,000 barrels or 122,180,000 gallons of highest grade gasoline. Considered as crude at $3 per barrel this volume has a value of $8,727,000, but as gasoline at 22 cents per gallon it has a value of $26,880,000.

The loss during lease storage in this one field represents 3 per cent of the total gasoline—four billion gallons—produced in the United States during 1919, and equals more than one-third of the total gasoline recovered in the natural-gas gasoline industry.

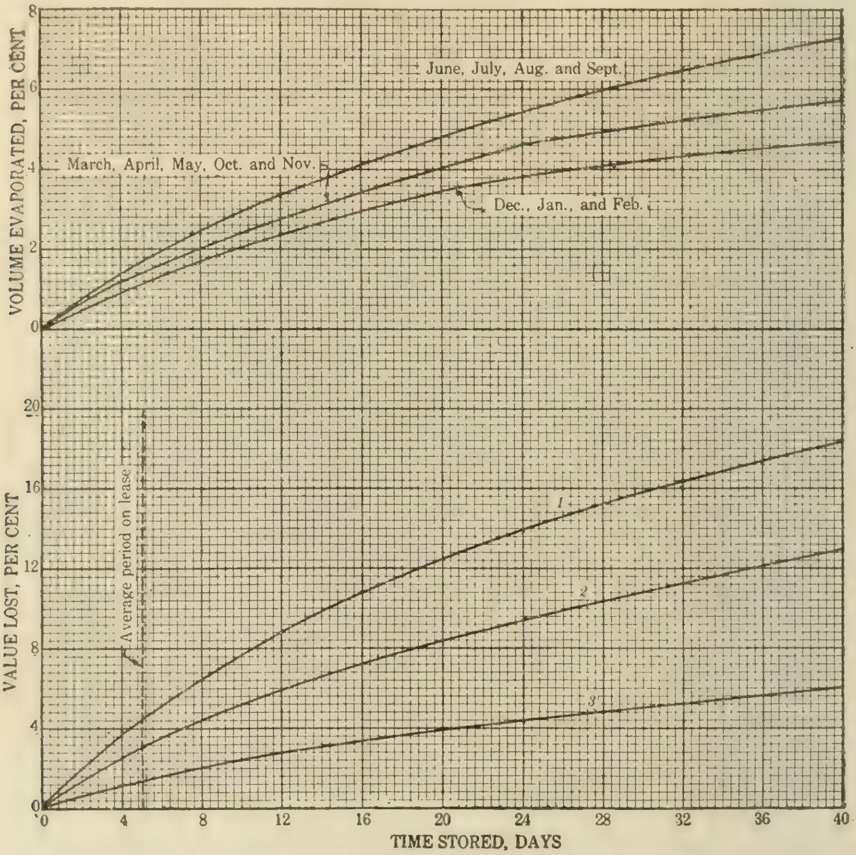


FIGURE 32.—Percentage of value lost by average tank (750 barrels) for the average season, including loss as gasoline at 22 cents per gallon v. crude at $3 per barrel, loss as gasoline at 22 cents per gallon v. refined products at $4.28 per barrel, and loss as crude v. crude. Percentage of volume lost by similar tank by seasons for any period of storage to 40 days on the Mid-Continent field.

The data from which the curves representing the percentage of volume lost by the average tank for each of the three seasons noted were calculated have been presented in Table 9. For example, this table shows that the 250-barrel size constitutes 31.78 per cent of the total tankage. After five days of storage at the average summer temperature, a tank of this size loses 2.8 per cent. Similarly, the proportion of the loss attributable to a 500-barrel and to a 1,600-barrel tank may be determined, each representing its proportion of the total loss by the "average tank." The sum of the three percentages so determined gives 100 per cent of the loss by the average tank for the season under consideration. The average per cent volume lost for any other season and any other period of storage may be determined in a similar manner. Results of such proportioning and averaging are shown in Table 15, under "Average tank."

CONDENSED DATA ON THE THREE PRINCIPAL TYPES OF TANKS.

Table 15 shows in condensed form results on the three main groups of tanks, giving percentage of volume, actual volume, and actual value lost through evaporation for varying periods of storage. It is certain that all the percentages shown in this table are very conservative. They are believed to represent the average condition in the Mid-Continent field.

TABLE 15.—*Percentage of volume, actual volume in barrels, and value in dollars lost as crude in various types of lease storage.*

Tank.		Percentage of total tankage.	Volume lost on—					Barrels lost.					Value lost as crude at $3 per barrel.				
Kind.	Size.		1st day.	3d day.	5th day.	10th day.	40th day.	1st day.	3d day.	5th day.	10th day.	40th day.	1st day.	3d day.	5th day.	10th day.	40th day.
SUMMER. [June, July, August, and September.]																	
	Bbl.		*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*										
Steel	250	31.8	0.80	1.93	2.8	4.55	10.90	1.9	4.6	6.7	10.9	26.2	$5.70	$13.80	$20.10	$32.7	$78.70
Do	500	33.4	.52	1.27	1.97	3.11	7.74	2.5	6.2	9.7	15.2	37.8	7.50	18.60	29.10	45.60	113.40
Wood	1,600	34.8	.20	.50	.7	1.18	3.67	3.0	7.5	10.5	17.7	55.1	9.00	22.50	31.50	53.10	165.30
Average	750	....	.50	1.21	1.79	2.90	7.33	3.8	9.1	13.4	21.7	55.0	11.40	27.30	40.20	65.10	165.00
AUTUMN AND SPRING. [March, April, May, October, and November.]																	
Steel	250	31.8	0.58	1.42	1.96	3.55	8.06	1.4	3.4	4.7	8.5	19.4	$4.20	$10.20	$14.10	$25.50	$58.20
Do	500	33.4	.41	1.03	1.60	2.68	6.20	2.0	5.0	7.8	13.1	30.4	6.00	15.00	22.40	39.30	91.20
Wood	1,600	34.8	.16	.43	.63	1.07	3.21	2.4	6.5	9.4	16.0	48.2	7.20	19.50	28.20	48.00	144.60
Average	750	....	.38	.95	1.38	2.39	5.75	2.8	7.1	10.3	17.9	43.1	8.40	21.30	30.90	53.70	129.30
WINTER. [December, January, and February.]																	
Steel	250	31.8	0.42	1.09	1.65	3.00	6.1	1.0	2.6	4.0	7.2	14.7	$3.00	$7.80	$12.00	$21.60	$44.10
Do	500	33.4	.30	.82	1.30	2.32	5.22	1.5	4.0	6.4	11.4	25.5	4.50	12.00	19.20	34.20	76.50
Wood	1,600	34.8	.12	.40	.57	.99	2.93	1.8	6.0	8.6	14.9	44.0	5.40	18.00	25.80	44.70	132.00
Average	750	....	.28	.76	1.16	2.07	4.70	2.1	5.7	8.7	15.5	35.2	6.30	17.10	26.10	46.50	105.60

YEAR.

Steel	250	....	0.61	1.51	2.16	3.75	8.52	1.5	3.6	5.2	9.0	20.4	$4.50	$10.80	$15.60	$27.00	$61.20
Do	500	....	.42	1.06	1.65	2.73	6.46	2.1	5.2	8.1	13.4	31.6	6.30	15.60	24.30	40.20	94.80
Wood	1,600	....	.16	.45	.64	1.00	3.28	2.4	6.8	9.6	15.0	49.2	7.20	20.40	28.80	45.00	147.60
Average	750	....	.39	.99	1.46	2.48	6.01	2.9	7.4	10.9	18.6	45.1	8.70	22.20	32.70	55.80	135.30

GENERAL DISCUSSION OF LEASE-STORAGE EXPERIMENTS.

In reviewing the lease-storage experiments, the fact that appears most striking and significant is that the protection of tanks by some device eliminating the circulation of air will decrease the evaporaton loss one-half to two-thirds, the actual saving being dependent upon the efficiency of the device. Evidently, a tank should never be filled with an overshot connection, and the oil should be taken off the lease as soon as possible after the tank is filled.

EVAPORATION LOSSES DURING STORAGE IN 37,000 AND 55,000 BARREL STORAGE TANKS.

East of the Rocky Mountains, about 80,000,000 barrels of oil is held in storage in large tanks, practically all of the oil produced being thus held for varying lengths of time. The losses by evaporation during such storage are, therefore, important.

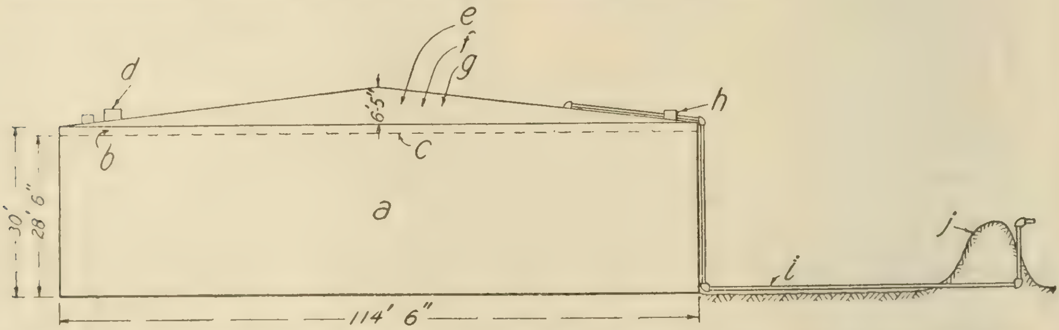


Figure 33.—Average conditions during storage in large steel tanks: *a*, 55,000-barrel steel tank; *b*, space allowed for expansion of oil in summer; *c*, level, average when full; *d*, opening for swing pipe; *e*, average volume of vapor above oil, 33,510 cu. ft.; *f*, average variation in temperature of vapor=25° F during 24 hours; *g*, average breaths of vapor=1,870 cu. ft. a day; *h*, 2 to 4 hatches 8-inch diameter; *i*, 6-inch pipe; *j*, fire wall.

LOCATION OF TESTS.

There was difficulty in finding a place where much oil was stored for great lengths of time, inasmuch as the consumption of the United States is somewhat greater than production and importation combined. However, such a place was found in the new Texas fields, where facilities for transporting the oil from the field were not adequate. There 80 tanks, mainly of the 55,000-barrel size, were obtained and records were kept for a period of 10 months.

EVAPORATIVE CONDITIONS IN 55,000-BARREL TANKS.

Figure 33 is a sketch which shows the principal features of such a tank, described by Bowie.[4] These large tanks are supposed to be gas tight. With very few exceptions, however, they are not, for the air has easy access at many points, such as hatch openings and swing-pipe openings, leaks around the edges of the roof, and often in the top of the roof itself. Many of these tank roofs leak rain but most of them do not, although at many such leakage hides much of the evaporation loss. Owing to the expansion and contraction of the air and vapor above the oil with variations of temperature, the tank alternately forces out and takes in a large volume of gasoline vapor and air during 24 hours. This is called breathing. A large pipe shown at the right in figure 33, conducts the vapors a short distance from the tank, in order to decrease the fire hazard, especially during thunderstorms. One of the theories on tank fires during thunderstorms is that lightning ignites the column of vapor rising from the oil and the burning vapor ignites the oil in the tank. With an average variation in temperature during 24 hours of about 25° F., and the assumptions shown in the figure, the "breathe" would be 1,876 cubic feet a day. When a tank is filled in winter a considerable space is always left at the top for the expansion of the oil during the following summer.

---

[4] Bowie, C. P., Oil-storage tanks and reservoirs with a brief discussion of losses of oil in storage and methods of prevention: Bull. 155, Bureau of Mines, 1917, 73 pp.

METHOD OF MAKING TESTS.

In order that more accurate results might be attained, a tank was gaged in three places and the average of the three gagings taken as the depth of oil in the tank at a stated instant. This procedure eliminated personal errors in reading the tape or recording. For temperature determination the points examined were 5, 15, and 25 feet from the bottom, or 6, 16, and 26 feet from the bottom. Samples taken from representative tanks at the beginning of each test, and periodically thereafter, were distilled by the standard method and used as a check on the volumetric readings.

RESULTS OF TESTS..

The results presented here are evolved from composite data on a number of tanks in each class, the classes being determined by size, color, and date of filling. In this way, tanks of the same size and color could be compared for evaporation loss from oil of different ages. Table 16 shows the resulting classification. Observe that class D is one year older than class A. Figure 34 gives the volume lost per tank from one test for classes A, B, C, and D; it shows that the oldest oil evaporates more slowly than the freshest oil, or that which is one year younger. Oils of intermediate ages show rates of evaporation falling between these two limits. Class A represents the loss of oil during its first year of storage. This curve, when continued, shows a loss of 3 per cent for the first year. Class D represents the loss from a similar oil during its second year which, when continued, equals 2.1 per cent. In other words, during the first two years of such storage the oil would lose about 5.1 per cent of its original volume.

This oil is of the type found near Ranger, Tex. Its gravity when it enters the tank is 40° B, its gasoline content about 31 per cent, having an end point in a straight distillation of the crude, of 392° F. Figure 38 shows the distillation record of a typical Ranger oil. By examining classes A, B, and C in figure 34 the reader will see that although the difference in age, four months, between B and C and A and B is the same, the increase in rate of evaporation between A and B is greater than the increase between B and C. In other words, the evaporation loss is larger for the fresh oil.

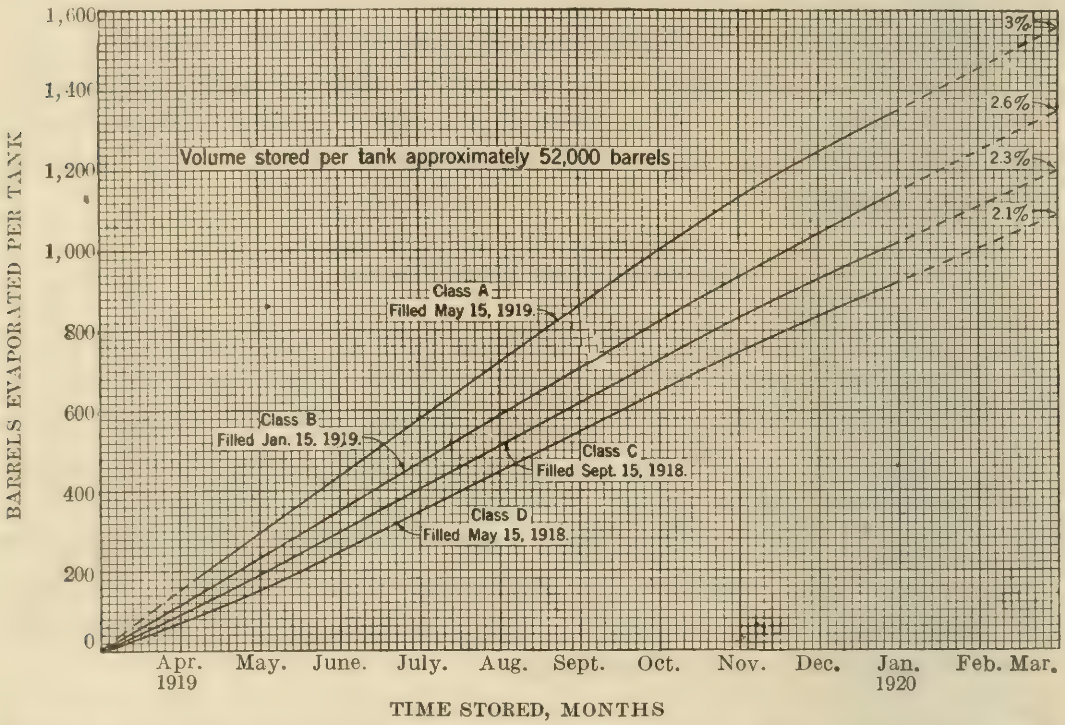


FIGURE 34.—Comparison of the rates of evaporation of oils of different ages. First test.

TABLE 16.—*Classification of 55,000-barrel tanks.*

Number of figure.	Class.	Color.	Date filled.	Number of figure.	Class.	Color.	Date filled.
34	A	Black	May 15, 1919	53	E_1	White	Mar. 15, 1919
34	B	do	Jan. 15, 1919	52	E_2	Red	June 21, 1919
34	C	do	Sept. 15, 1919	52	F	do	Mar. 18, 1919
34	D	do	May 15, 1918	52	G	do	Sept. 10, 1919

Figure 35 embodies the result of very careful tests at several 55,000-barrel tanks over a period of three months. Here, again, the rate of loss is less for the older than the fresh oil. The rate for oil of intermediate age is between the two.

Figure 36 gives the combined loss by evaporation from 30 tanks storing 1,440,235 barrels. In one year the loss was 32,100 barrels of gasoline, with a value of $297,000 as gasoline at 22 cents per gallon or $96,300 as crude at $3 per barrel. This represents a yearly loss of $9,900 as gasoline or $3,210 as crude for each 55,000-barrel tank. The oil tested was of various ages, one year and less. The total volume lost in a year was 2.23 per cent. All tanks that showed any leakage were eliminated from this summation.

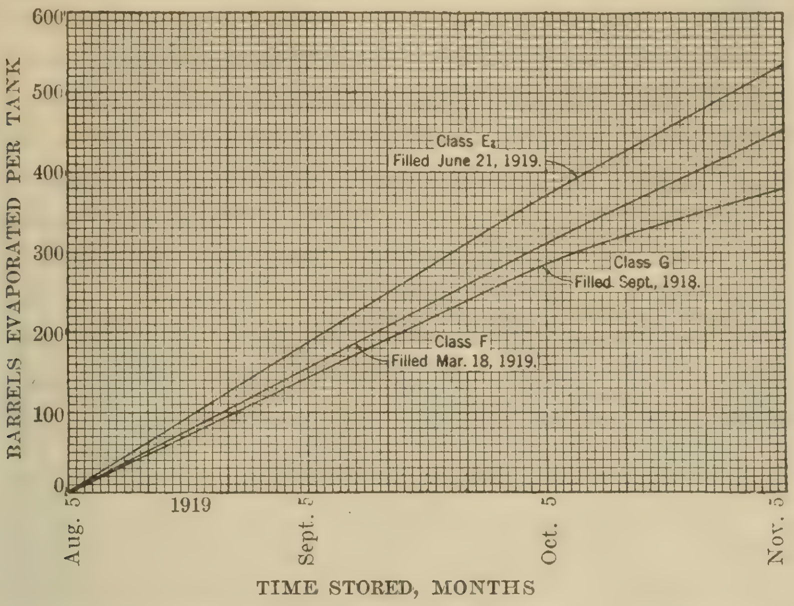


Figure 35.—Comparison of the rates of evaporation of oils of different ages stored in 55,000-barrel tanks. Second test.

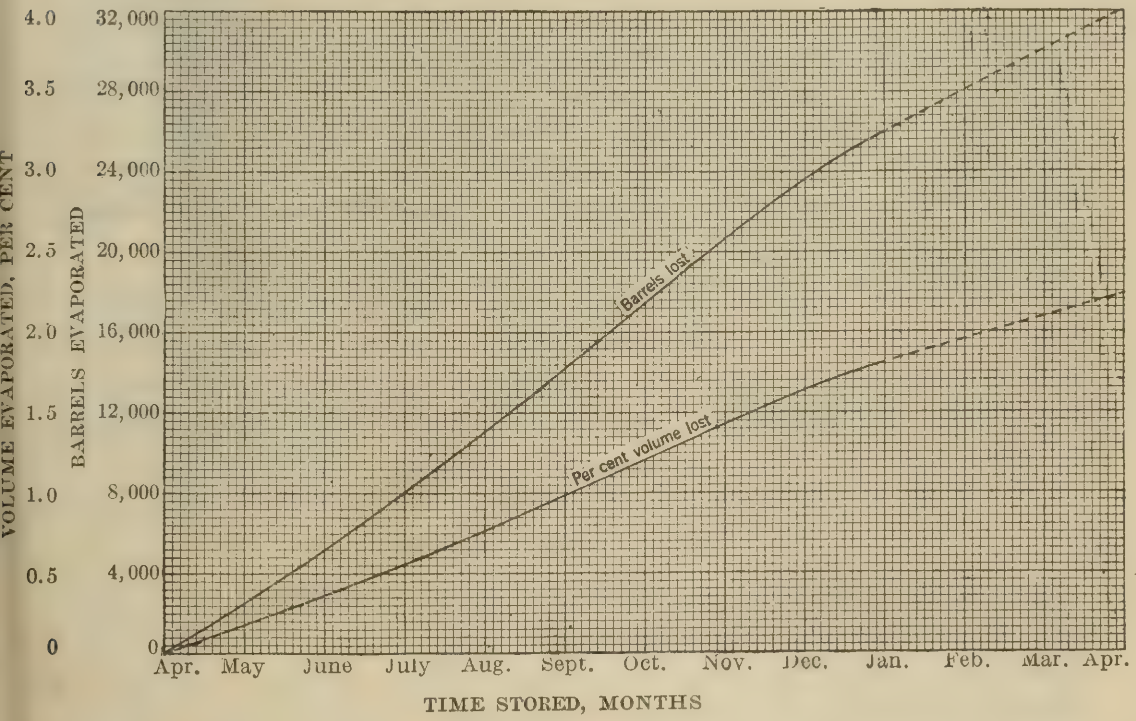


Figure 36.—Results of test made on 1,440,235 barrels stored in standard steel 55,000-barrel tanks showing loss from evaporation. Age of oil, 1 year and less.

COMPARISON OF WHITE AND BLACK TANKS.

Whether tanks should be painted white to decrease evaporation is an old problem. Experiments performed a few years ago by D. S. Bushnell, now president of the New York Transit Co., proved that the temperature of oil in tanks painted white is 8 to 10° F. lower than that of oil in black tanks. Red tanks were little better than black, the temperature difference being but 2° F. In these tests, however, the effect of lower temperature on evaporation was not determined. The only available data covering the relative value of black and of white paint are grouped in figure 37. A small difference appears in favor of the white tank, statistics indicating that in nine months a 55,000-barrel white tank would save 85 barrels more of oil than a black tank. If this saving be taken as gasoline it represents $785; if taken as crude, $255. The age of the oil in the white tank is somewhat less than that in the black; thus, under exactly the same conditions, the oil in the white tank should have shown a more rapid rate of evaporation than that in the black tanks. It seems, however, that the white tanks more than overcame this tendency.

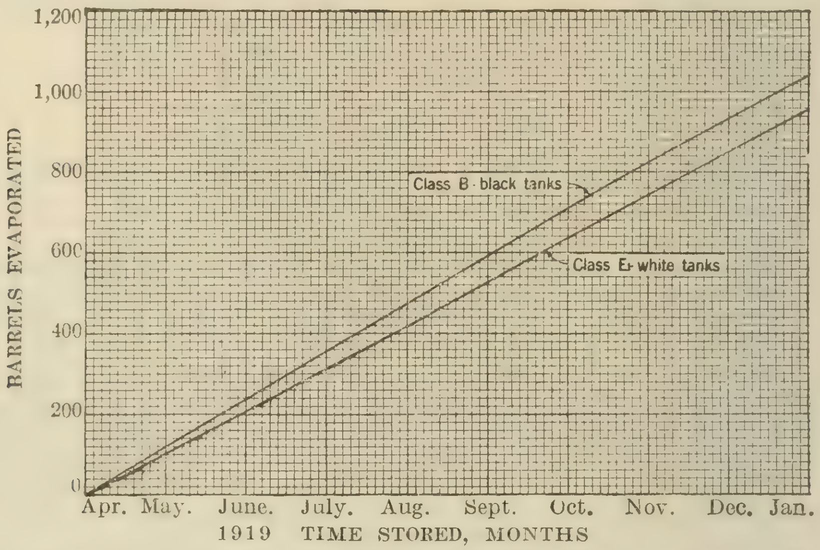


FIGURE 37.—Comparison of volume evaporated from black and from white 55,000-barrel tanks.

CHECK BY DISTILLATIONS.

All results from volumetric measurements were checked by distillation of samples from the same tank. The period under observation was two months, but even for so short a period the percentage of volume lost was quite evident. The gravity of the oil fell 0.2° B.—from 39.2° B. to 39.0° B.—and the gravity of the portion lost was 82° B. These results checked very closely those from measurements in the field.

All of the oil placed in the 80 large tanks under observation came from the same general horizon in the same field, hence it was nearly uniform in quality, with about the same specific gravity when fresh from the well. Composite results of distillations from numerous samples taken on the same date and covering the three classes A, B, and D are shown in figure 38. Assume the oils to be, respectively, identical at the start of storage. From January 15 to May 15, 1919, there was 1 per cent volumetric loss; from May 15, 1918, to May 15, 1919, there was 3.6 per cent, which approximately checks the 3 per cent loss determined by the field test and shown in figure 34 for class A. The gravity of the portion lost varied from about 84° B to 78° B.

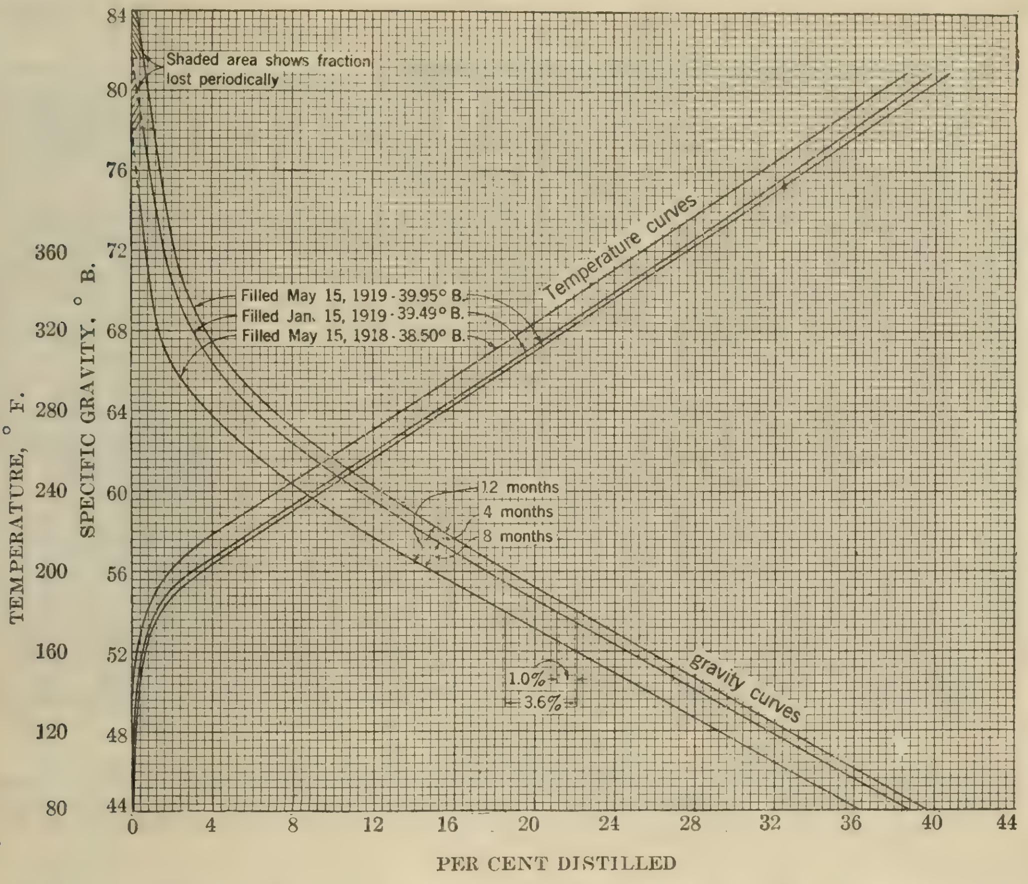


FIGURE 38.—Composite results of distillations of oil of different ages in 55,000-barrel tanks, showing the effect of evaporation. Samples of Ranger crude taken on July 30, 1919, four from each age.

MISCELLANEOUS DATA ON LARGE TANKS.

OIL TEMPERATURES THROUGHOUT TANK.

In order to ascertain the difference in the temperature of the oil in the tank, temperatures were taken on the bottom and at 1, 2, 5, 10, 15, 20, and 25 feet from the bottom. In addition, temperatures were taken at the surface, 6 inches below the surface, and in the vapor above the oil. These data for different dates and different average temperatures of the oil are shown in figure 39. The average temperature of the oil may be only about 86° F., whereas the temperature of the surface may be 95° F. or even higher, this surficial heating being caused by the sun's rays beating upon the dark metal roof. On a hot summer day the temperature of the vapor above the oil may be as high as 125° F. With the coming of cooler weather, this great difference between average temperature and surface temperature decreases. In summer the comparatively cool bottom is caused by a small depth of B. S. which does not circulate and is kept cool by the ground.

Data were gathered (see fig. 40) showing the changes of temperature in the oil and in the air space above the oil in a 55,000-barrel tank throughout an average summer day. For the vapor, the maximum temperature difference was 35° F., which is higher than the average for the year. Such difference of temperature makes it easy to see why the rate of evaporation may be much higher than it has been thought to be. A surface temperature of 102° F. is common for a few hours each day during the three or four summer months. This high temperature of the surface oil is caused by that of the vapor.

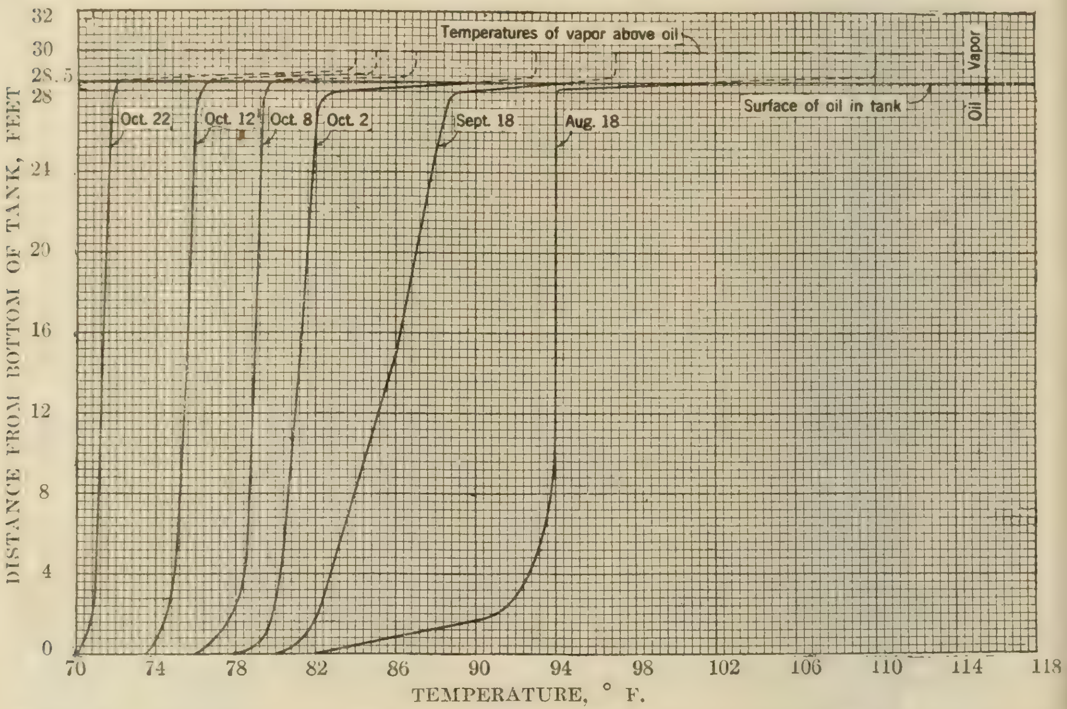


FIGURE 39.—Variation of oil temperatures from the bottom to the oil surface in a 55,000-barrel tank for summer and autumn. Corresponding temperature of mixture of vapor and air above oil. Clear days—3 o'clock p. m.

POSSIBLE ACCURACY OF OBTAINING OIL TEMPERATURES.

The expansion of oil with rise of temperature and the daily variation of 1.5° F. for the whole tank show how necessary it is to get accurate temperatures at the time of gaging, as the actual volume of oil in the tank under consideration varied approximately 40 barrels during that day.

A test was designed to show the possible accuracy of taking temperatures with thieving thermometers of the type described on page 24. Two such thermometers were used. They were lowered at the same instant to the desired depth, each being handled and read by a different man, and all operations being simultaneous. The thermometer could not be read closer than 0.2° F., but readings were estimated to the nearest 0.1° F. The comparative results are given in Table 17,

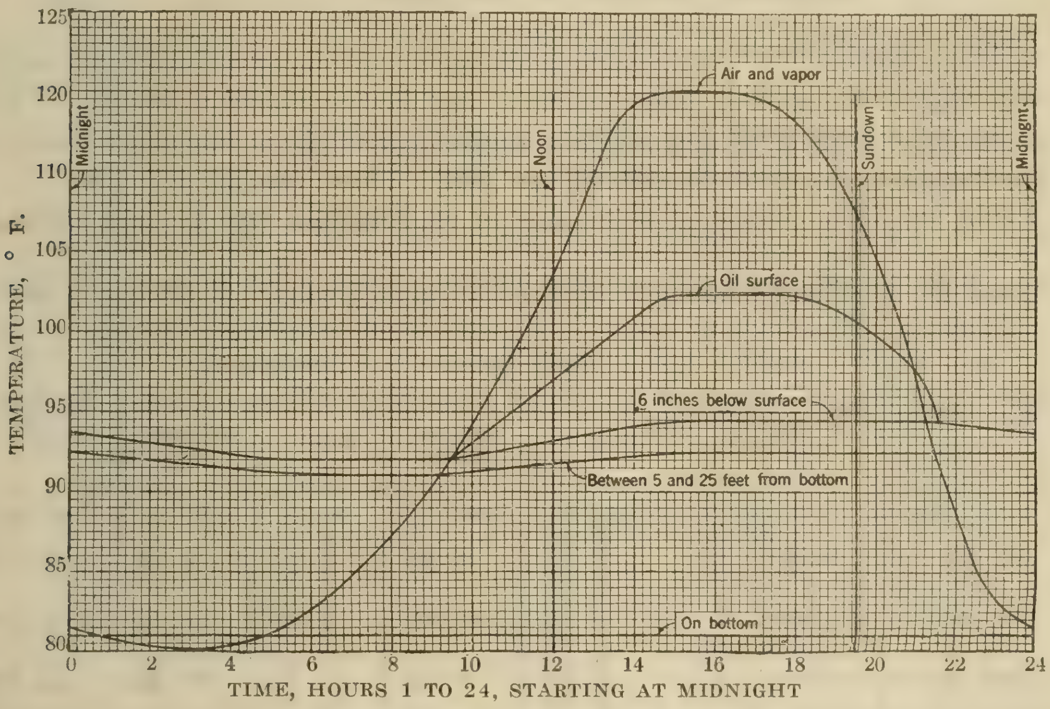


FIGURE 40.—Oil and vapor temperatures throughout the day for 55,000-barrel steel tank, Aug. 11, 1919.

TABLE 17.—*Temperature comparisons in 55,000-barrel tanks with thieving thermometers, showing possible accuracy.*

Tank No.	Hatch.	Date.	Hour.	5 feet.		15 feet.		25 feet.		Average.	
				Thermometer D.	Thermometer A.	Thermometer D.	Thermometer A.	Thermometer D.	Thermometer A.	Thermometer D.	Thermometer A.
		1919.		°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
921	A	Oct. 2	12.00	81.7	81.5	82.2	82.0	82.7	82.5	82.2	82.0
922	A	...do..	13.45	81.9	82.0	82.7	82.8	83.7	83.5	82.8	82.8
881	A	...do...	15.00	82.2	82.0	83.2	82.9	83.7	83.2	83.0	82.7
922	B	Oct. 3	14.15	82.1	82.0	82.5	82.7	83.4	83.2	82.7	82.6
922	C	...do...	14.30	82.0	82.1	82.5	82.9	83.2	83.5	82.6	82.8
922	D	...do...	15.00	81.6	82.0	82.5	82.8	83.2	83.2	82.4	82.67
924	A	Oct. 5	14.15	82.0	82.0	82.5	82.7	82.6	82.9	82.3	82.5
924	B	...do...	14.40	81.9	82.1	82.5	82.7	82.8	82.8	82.4	82.5
924	C	...do...	15.00	82.1	82.2	82.5	82.6	83.1	83.3	82.6	82.6
924	D	...do...	15.15	82.1	82.1	82.6	82.6	83.1	83.0	82.6	82.7
Average	....	....	....	82.0	82.0	82.5	82.7	83.2	83.11	....	....

which shows that in only one reading were the observed temperatures 0.5° F. apart. In two readings they were 0.4° F. apart; in four readings, 0.3° F. apart; and in the other readings, 0.2° F. or less. The columns of the average of the three depths show a maximum difference of 0.3°F., and a usual difference of 0.2° F. or less. With the thieving thermometer and ordinary care, the average temperature of the tank should be determinable to 0.3° F., or, with more readings, to 0.2° F., which would give a possible error of 5 barrels in a full tank.

POSSIBLE ACCURACY OF MEASURING OIL DEPTH.

The possible accuracy of the gaging was next considered. A tank was gaged at three or four different hatches at marked points. The same tape was used for all work and readings were estimated to the nearest one-sixty-fourth of an inch. The results are shown in Table 18. The work of one man is represented by X, that of the other by Y. The maximum difference of the average columns is one thirty-second of an inch, representing 4 barrels.

TABLE 18.—*Readings showing possible accuracy of gaging a 55,000-barrel tank.*

Tank No.	Date.	Hour.	Position.	Work of X.[a]				Work of Y.[a]				Difference, $Y-X$.	
				Depth.		Average depth.		Depth.		Average depth.			
	1919.			*Ft.*	*In.*	*Ft.*	*In.*	*Ft.*	*In.*	*Ft.*	*In.*	*In.*	*Bbl.*
921	Oct. 2	12.00	A	28	$4\frac{7}{16}$	28	$3\frac{53}{64}$	28	$4\frac{15}{32}$	28	$3\frac{54}{64}$	$+\frac{1}{64}$	2.4
			B	28	$3\frac{5}{16}$			28	$3\frac{5}{16}$				
			C	28	$3\frac{3}{4}$			28	$3\frac{3}{4}$				
881	...do.....	15.00	A	28	$4\frac{3}{64}$	28	$4\frac{41}{64}$	28	$4\frac{15}{32}$	28	$4\frac{40}{64}$	$-\frac{1}{64}$	2.4
			B	28	$4\frac{27}{32}$			28	$4\frac{27}{32}$				
			C	28	$4\frac{9}{16}$			28	$4\frac{9}{16}$				
924	...do.....	15.50	A	27	$5\frac{21}{32}$	27	$5\frac{35}{64}$	27	$5\frac{21}{32}$	27	$5\frac{36}{64}$	$+\frac{1}{64}$	2.4
			B	27	$5\frac{27}{32}$			27	$5\frac{55}{64}$				
			C	27	$5\frac{7}{32}$			27	$5\frac{3}{16}$				
919	Oct. 3	12.30	A	28	$\frac{25}{32}$	28	$\frac{30}{64}$	28	$\frac{13}{16}$	28	$\frac{32}{64}$	$+\frac{1}{32}$	5.0
			B	28	$\frac{11}{32}$			28	$\frac{3}{8}$				
			C	26	$\frac{19}{64}$			28	$\frac{5}{16}$				
889	...do.....	10.40	A	26	$10\frac{5}{16}$	26	$9\frac{38}{64}$	26	$10\frac{11}{32}$	26	$9\frac{39}{64}$	$+\frac{1}{64}$	2.4
			B	26	$8\frac{19}{32}$			26	$8\frac{39}{64}$				
			C	26	$9\frac{7}{8}$			26	$9\frac{7}{8}$				
922	...do.....	13.45	A	28	$7\frac{13}{64}$	28	$7\frac{30}{64}$	28	$7\frac{7}{32}$	28	$7\frac{30}{64}$	0	0
		14.15	B	28	$7\frac{9}{32}$			28	$7\frac{1}{4}$				
		14.30	C	28	$7\frac{15}{16}$			28	$7\frac{59}{64}$				
929	...do.....	3.45	A	28	3	28	$2\frac{44}{64}$	28	$2\frac{31}{32}$	28	$2\frac{43}{64}$	$-\frac{1}{64}$	2.4
			B	28	$2\frac{3}{4}$			28	$2\frac{3}{4}$				
			C	28	$2\frac{5}{16}$			28	$2\frac{5}{16}$				

[a] X represents one man, Y another.

COMBINED ERROR IN OBTAINING VOLUME OF OIL IN TANK.

Tables 17 and 18 show that the combined error of gaging and temperature is 9 barrels. From this it can be said positively that the difference in volume of a single 55,000-barrel tank full of oil can be determined within 15 barrels when volumes are calculated for

60° F. if sufficiently careful means be used to gage temperatures and depths.

VOLUMETRIC VARIATION OF VAPOR ABOVE OIL.

Table 19 shows what the volumetric variation of the vapor above the oil is for different depths of oil. It is estimated that 250,000 cubic feet of a mixture of air and gasoline vapor are expelled when a 55,000-barrel working tank on a pipe line is filled. If this vapor is 20 per cent gasoline vapor, at 35 cubic feet per gallon the loss is 1,428 gallons, or 34 barrels, or 0.062 per cent of the full tank of oil. In other words, with most light oils the filling of a 55,000-barrel tank costs 34 barrels of gasoline, valued at $102 as crude or $314 as gasoline.

EVAPORATION LOSSES IN TRANSFERRING OIL FROM LEASE TO REFINERY BY TANK CAR.

Ordinarily the production from many leases and producing companies is so mixed early in the journey to the refinery that it is difficult to find at a refinery the oil from a single lease or combination of leases unmixed with oil from other leases. Such unmixed oil, however, was found at two refineries and data regarding it were collected.

TABLE 19.—*Volume of air above oil in a 55,000-barrel tank and its thermal expansion for various conditions.*

Depth of oil.	Volume of air above oil.	Expansion.			
		Per ° F.	Per 10° F.	Per 20° F.	Per 30° F.
Feet.	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*
30	22, 320	42	420	848	1, 260
29	32, 630	62	620	1, 240	1, 860
28½	37, 790	72	720	1, 440	2, 160
27	53, 250	101	1, 010	2, 020	3, 030
26	63, 560	121	1, 210	2, 420	3, 630
25	73, 870	140	1, 400	2, 800	4, 200
20	125, 420	238	2, 380	4, 760	7, 140
15	177, 020	336	3, 360	6, 720	10, 080
10	228, 520	434	4, 340	8, 680	13, 020
5	280, 320	532	5, 320	10, 640	15, 978

FIRST TEST.

LAYOUT.

The first of these tests deals with oil of 40° B. from the Mervine field near Ponca City, Okla. The daily production, only 200 barrels, is run from the lease every other day, being stored there in 250-barrel tanks until a day's run of about 400 barrels is obtained. It is pumped through 14 miles of 3-inch covered pipe line and emptied into a 7,000-barrel steel tank by overshot connections. From this 7,000-barrel tank the course of the oil divides. Part of the oil is pumped into tank cars (see Pl. II, *B*, p. 33) and hauled 100 miles to a refinery, where it is pumped into a large steel tank. The rest of the oil in the 7,000-barrel tank is pumped one-fourth of a mile through a 6-inch covered pipe line to another large steel tank, capacity 10,000 barrels, at the refinery. Where possible, the loss at each stage was determined, as from lease tanks to pipe-line tank, pipe-line tank to tank car, en route to refinery, and tank car to refinery tank. The loss from pipe-line tank to refinery tank through pipe was considered separately under the heading "Filling a large steel tank with bottom connections."

RESULTS.

Table 20 shows the apportionment of losses in "lease to refinery" test. There are at least four reasons for the large percentage of volume lost from lease to pipe-line tank. First, the volume of oil handled is small; second, this is held in two 250-barrel exposed tanks during the time that it is being taken from the lease, and the loss during this time is charged to the whole process of gathering. Third, the period of time needed for emptying the two 250-barrel tanks—that is, for handling 400 barrels—is about 24 hours. This means that a very small stream is falling an average distance of 13 feet into a large tank, which allows considerable evaporation, although it has a steel roof. Fourth, the area of this large receiving tank is great compared to the volume of oil that enters at any one period. These facts help to account for an average loss of 50.4 barrels, or 6.3 per cent, in running 800 barrels. Two tests made over this part of the layout checked each other very closely.

TABLE 20.—*Results of first test—lease to refinery.*[a]

Stage of handling.	Time elapsed.	Volume lost.
	Days.	*Per cent.*
Lease to pipe line tank	1	6.32
Pipe line to tank car	$\frac{1}{6}$	.30
Tank car en route	13	.63
Emptying tank car	$\frac{1}{6}$	.50
Total	$14\frac{1}{3}$	7.75

[a] No loss from well to end of lease storage is included. Gravity of oil at well, 41° B.

SECOND TEST.

LAYOUT.

The second test was with the oil from the Garber field in Oklahoma. This oil has a much higher gravity than the average

Oklahoma oil, because it contains a large proportion of medium gravity gasoline. It has a comparatively small proportion of the very light fractions. Although the gasoline content at the lease tank is as high as 50 per cent, with an end point of 392° F., the first 1½ per cent distilled shows a gravity of 83.3° B., whereas Kansas oil of 37° B. gravity shows for the first 1½ per cent distilled a gravity of 79° B. At 6 per cent over, the gravity of the Garber distillate is 72° B., whereas that of the Kansas oil is 68° B. These facts and others presented in Part III show that an evaporation test of this light oil gives a basis for comparison with the average oil of the Mid-Continent field.

Figure 41 is a sketch of the layout for this test. The oil from four leases was brought to a central pumping station and from there carried through 3 miles of covered 3-inch pipe line. At that point part of it went through 7 miles of 3-inch exposed line, and the remainder went through 2½ miles of 3-inch covered line. Whichever way it went, the oil was either stored in steel tanks for a short period or pumped directly into tank cars. These cars were hauled 150 miles to the refinery, where the oil was pumped into a 15,000-barrel steel tank. The loss was determined at each stage of progress and checked by samples taken on the lease, at the pipe-line gathering tanks, and in the tank cars. Accurate measurements of volume were made at each movement of the oil.

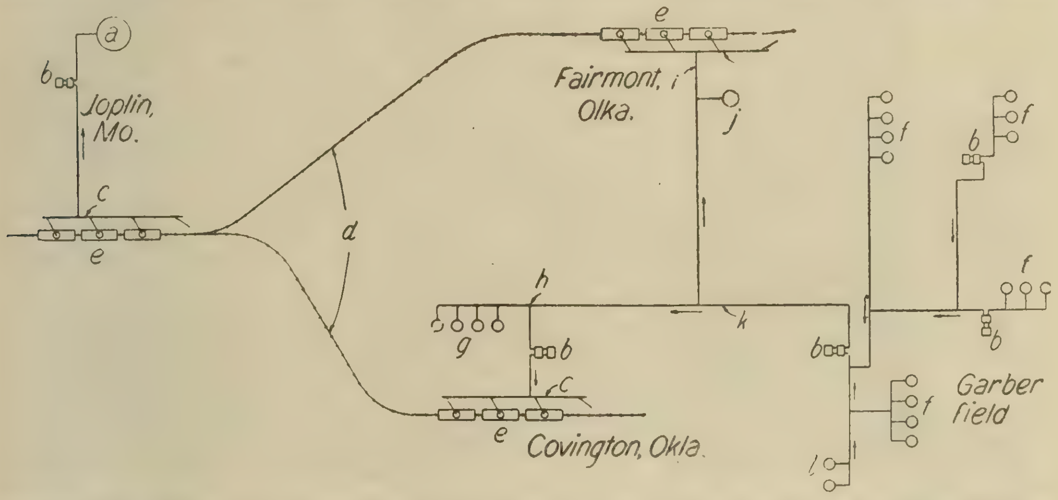


FIGURE 41.—Layout for determining evaporation loss in handling oil from lease to refinery by tank car. Second test: *a*, 1,500-barrel steel tank at refinery; *b*, pump; *c*, loading rack; *d*, 200 miles railroad; *e*, tank cars; *f*, 250-barrel covered steel lease tanks; *g*, 100-barrel unprotected steel gathering tanks; *h*, 2½ miles 3-inch covered pipe; *i*, 7 miles 3-inch unprotected pipe; *j*, 500-barrel unprotected steel gathering tank; *k*, 3 miles 3-inch covered pipe; *l*, 250-barrel unprotected steel leased tank.

FIELD WORK.

The field work does not consider any of the losses to which the oil was subjected before it left the lease; they are shown from distillations or representative samples taken at successive points in the journey from the well. After leaving the well the oil passed through a gas trap kept under suction, and the gasses separated went to a compression gasoline plant. From the gas trap the oil splashed into a flow tank and from that it splashed by overshot connections into lease tanks. The reader should note that the average over-all time that a barrel of oil was under consideration in the field test was only eight and one-third days. A special test showed that the volume of dissolved gas carried by the oil in the lease tank was very small, only 0.11 per cent of the volume. (See Part III.) Any wild gas in the oil at the well was removed by the vacuum in the gas trap. Consequently, the loss shown as evaporation is a recoverable fraction.

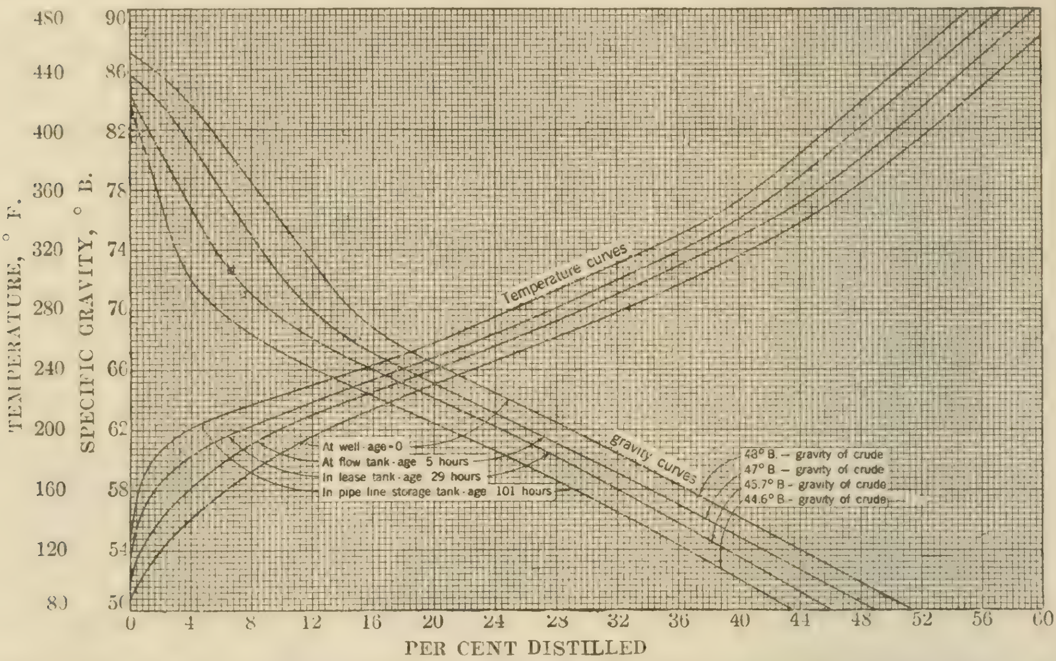


FIGURE 42.—Effect of evaporation as shown by distillation curves on second "lease to refinery" test.

RESULTS FROM DISTILLATIONS.

Samples were taken at several wells closely representative of the average production. At the flow tank another sample, representing even more closely the average production of the lease, was taken. At the same time, another sample was collected at the lease storage tank after it had stood full for 24 hours. Subsequently, another sample was taken at the pipe-line storage tank at the railroad. Results of distillation tests of these samples appear in Table 21. Figure 42 is a striking diagram illustrating the ravages of evaporation on light oils when handled as they are at present.

TABLE 21.—*Results of second test showing percentage of volume lost by evaporation during movement of oil from well to refinery.*

Stage of handling.	Change of °B. of crude.		Time elapsed.	Per cent volume lost.			
				By formula.	Graphically.		By field test.
	From—	To—			Gravity curves.	Temperature curves.	
			Days.				
Well to flow tank	48.0	47.0	$\frac{5}{24}$	3.0	2.6	2.6	(*a*)
Flow tank to lease tank	47.0	45.7	1	4.0	2.5	2.1	(*a*)
Lease tank to pipe-line tank	45.7	44.6	4	3.7	3.0	2.6	2.9
Pipe-line tank to tank car	....	....	⅙	....	....	....	.3
Tank car en route	....	....	4	....	....	....	.5
Tank car to refinery tank	....	....	⅙	....	....	....	.5
Total—lease tank to refinery tank	....	....	8⅓	....	....	....	4.2
Total—well to pipe-line tank	48.0	44.6	5¼	10.7	8.1	7.3	....
Total—well to refinery tank	....	....	9½	....	9.4	8.6	9.0

a Undetermined.

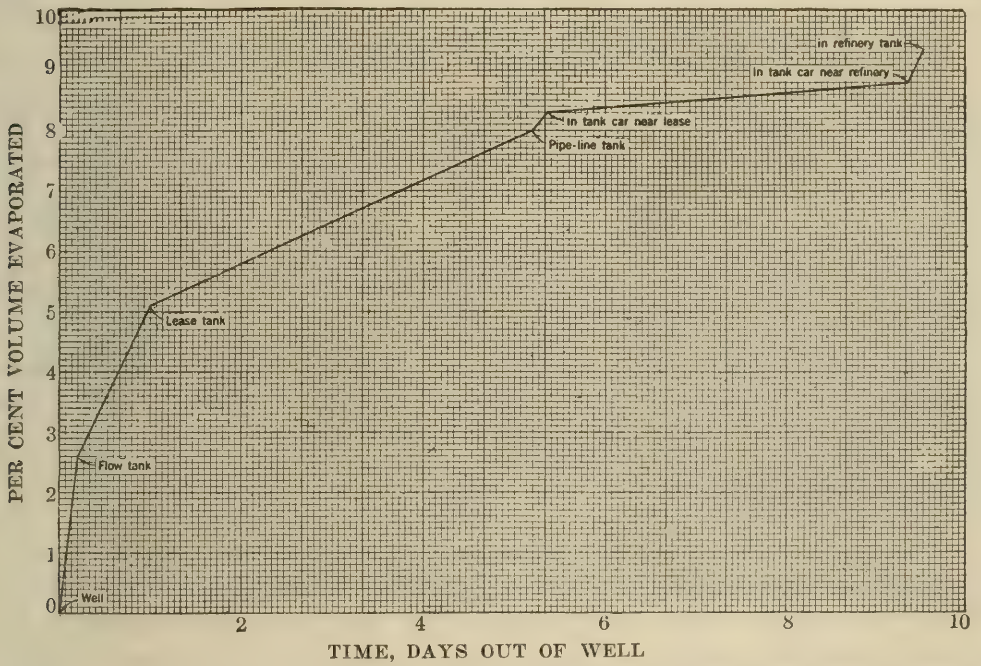


FIGURE 43.—Percentage of volume lost by oil through evaporation, by stages, from well to refinery. Second test.

DISCUSSION OF RESULTS.

The percentage of volume lost from the well to the refinery shown in Table 21 and figure 43 has been obtained by combining the results of the distillations and the field measurements. These data show that oil evaporates rapidly at first, but gradually slower. A tank car evidently gives the best condition of storage, because it is fairly air-tight. When oil is moved from one tank to another the rate of evaporation is rapid.

Naturally, the greatest single loss is in gathering the oil from the lease tanks to the pipe-line tanks, because of the exposure during filling and while standing in unprotected steel tanks. The loss in filling the tank car is less than in emptying it—0.3 per cent as compared to 0.5 per cent—because the area of oil exposed in the car is very much smaller than that exposed in the large receiving tank. All of the loss at a large receiving tank during the emptying of the tank car is charged to the volume of oil emptied from the car. The over-all loss from lease to refinery under these conditions of storage and transportation (exclusive of losses on the lease) is 4.5 per cent. This figure is believed to be very nearly correct. Figure 61 (p. 106) compares the results of distillation tests of average Mid-Continent oil and Garber oil.

EVAPORATION LOSSES IN FILLING A 10,000-BARREL STEEL TANK.

METHOD OF TEST.

Before the tests to determine evaporation losses in filling a 10,000-barrel tank were begun care was taken to see that all connections were full of oil. To this end, the centrifugal pump was started, run for five minutes, and stopped, and a gage and temperature taken at tanks A and B. Thus, the volume of oil at 60° F. was accurately known at the beginning of the test in each tank. The pump was run for a number of hours until tank A was nearly empty. Immediately volumetric readings were again taken at tanks A and B. Had there been no loss the volume pumped out of A should have equaled the volume pumped into B.

RESULTS.

Table 22 shows that the loss in this test was three-tenths of 1 per cent, volumetrically. There was loss by evaporation from the tank that was being emptied as well as from the tank that was being filled. These losses were added and charged to the volume of oil that changed place, thus giving a basis for estimating the loss in main-line pumping stations when the oil is pumped into and from working tanks. The oil handled had a gravity of 39° B. and was about 25 days old at the beginning of the test. It had passed through the lease tanks and had been gathered by the pipe line into tank A.

In filling the tank there was a loss of 12 barrels, worth $36 if considered as crude, or $111 if considered as gasoline. This percentage of volume lost checks similar experiments made elsewhere.

TABLE 22.—*Results of test—filling a 10,000-barrel tank, Aug. 21, 1919.*

Item.		Start.	Finish.
Hour		8.40 a. m.	8.15 p. m.
Tank 1:			
Volume standing in tank	barrels	5,379.7	1,295.5
Volume pumped out	do		4,084.2
Tank 2:			
Volume standing in tank	do	3,101.4	7,173.6
Volume pumped in	do		4,072.2
Loss	do		12.0
Loss	per cent		0.3
Value lost:			
As crude, at $3 per barrel	dollars		36
As gasoline, at 22 cents per gallon	do		111
Gasoline v. crude	per cent		0.92

GENERAL DISCUSSION OF ALL RESULTS.

APPORTIONMENT OF LOSS—WELL TO REFINERY.

Table 23 shows the apportionment of the average losses sustained by crude oil in the Mid-Continent field on its journey from the well to the refinery for the year. These losses are based on all the information gathered in this work. The percentage of volume lost at two of the points, for example, at the flow tank, has necessarily been estimated. The loss in filling a lease tank was shown in two tests, made in summer, to be approximately 1.6 and 2.3 per cent. For the entire year the loss would be somewhat less; hence an average of 1 per cent is taken. The loss in the flow tank will certainly be as great as the loss in filling the lease tank, for the oil is fresher and the conditions are nearly the same. The average for lease storage is the result of numerous experiments and is believed to be very conservative. The percentage shown for the gathering system is based upon tests, due allowance being made for the test having been run in summer. It is believed that the transportation loss, estimated from information on filling large tanks and transportation by tank cars, is somewhat greater than the table shows. The loss on tank farms is calculated from the tests and from data on how long oil is ordinarily stored in large tanks.

TABLE 23.—*Apportionment of the loss sustained by crude from the well to the refinery.*

Location of loss.	Per cent volume evaporated.				Source of information.
	Summer.	Autumn and spring.	Winter.	Average.	
Flow tank	1.2	1.0	0.8	1.0	Estimated with help of lease tank test.
Filling lease tank	1.2	1.0	.8	1.0	Test.
Lease storage	1.8	1.4	1.2	1.5	Do.
Gathering	1.3	.9	.8	1.0	Do.
Transportation	1.2	.9	.8	1.0	Estimated with help of tank-car tests and of filling large tank.
Tank farms	.9	.7	.6	.7	Test.
Total	7.6	5.9	4.9	6.2	

Table 24 shows the monthly production and stocks of the Mid-Continent field for part of 1918 and 1919, as given by the U. S. Geological Survey. All the stocks are continually changing location, but it is approximately true that the oil is held in storage for a period determined by dividing the stocks by the total production, the resulting average being 5.1 months. From the experiments on large tanks, the figure of 0.7 percentage of volume lost for a storage period of 5.1 months seems conservative. The total of 6.2 per cent represents the loss to which a barrel of oil is subjected in all of the stages covered by Table 24.

This figure of 6.2 per cent, when applied to the 196,000,000 barrels produced in the Mid-Continent field, gives the yearly evaporation bill of 12,152,000 barrels, or 510,000,000 gallons, which was just about one and one-half times the total gasoline output of the natural-gas gasoline industry in the whole United States during 1919.

The determination of losses on main lines is most difficult. Lack of time and opportunity prevented thorough examination of this problem, which will be taken up later.

TABLE 24.—*Average time of storage of crude by pipe-line companies, Mid-Continent field.*

Month.	Marketed production.	Stocks.	Average months stored.
1918.	*Barrels.*	*Barrels.*	
September	13,998,000	89,120,000	6.36
October	14,988,000	87,095,000	5.8
November	13,784,000	83,275,000	6.0
December	13,115,000	30,047,000	6.1
1919.			
January	15,027,000	80,252,000	5.3
February	13,211,000	78,107,000	5.9
March	14,629,000	79,183,000	5.4
April	14,048,000	79,567,000	5.7
May	14,492,000	77,652,000	5.3
June	16,613,000	80,511,000	4.9
July	18,680,000	85,421,000	4.6
August	18,251,000	81,454,000	4.5
September	18,649,000	82,868,000	4.4
Average			5.1

DECREASE OF EVAPORATION LOSS.

Results of the tests show that by protecting lease tanks from circulation of air the amount of evaporation can be reduced one-half to two-thirds and perhaps more, depending upon the quality of the protection. Housing a steel tank reduces evaporation about one-half. An approximately air-tight jacket around a steel tank decreases evaporation even more.

VALUE OF PROTECTING TANKS.

Table 25 gives a comparison of the value of housing 250-barrel tanks and jacketing 500-barrel steel tanks. It is seen that, even though the jacket on a 500-barrel tank costs $360, the saving attained will pay for it in less than $3\frac{1}{2}$ months, whereas the house for the 250-barrel tank pays for itself in $2\frac{6}{10}$ months. These figures seem to show that housing was more valuable than the jacketing. This, however, is not the case, for the jacket on a 500-barrel tank is saving $19.20 every five days, whereas the house is saving only $13.80 every five days.

TABLE 25.—*Saving attained by protection of tanks by housing or jacketing.*

	Value of crude lost.	Saved (by protection) per 5 days.	Saving per month.	Cost of protection.	Time needed to pay for protection.
500-barrel steel tank:					*Months.*
Unprotected	$29.10	$19.20	$105.20	$360.75	3.43
Jacketed	9.90				
250-barrel steel tank:					
Unprotected	20.40	13.80	82.80	215.00	2.6
Housed	6.60				

CONCLUSIONS.

At present the most practicable way of reducing evaporation loss is to make the tops of all tanks gas tight and to keep them under a slight pressure, regulated by automatic valves. To make the roofs of steel tanks gas tight would be easy. Oil should be forced into a tank through the bottom and not through overshot connections. Where piping is already installed for a gasoline plant, all tanks should be connected to this system and kept under suction. Practically 100 per cent of the evaporation loss could be saved in this way. Whether it would pay better to put in a gasoline plant than to protect the tanks and keep the gasoline in the oil is a problem that each producer should work out for himself. Any man who handles crude oil has an evaporation problem. He should determine the amount lost and take steps to eliminate as much of the loss as possible. As the demand for petroleum products becomes stronger and prices rise again the need of preventing evaporation will be brought to his attention more and more.

ADDITIONAL WORK ON EVAPORATION.

Additional work on evaporation should proceed in two directions. One of these is toward getting further data on losses, especially in working tanks and main pipe lines. The other is toward determining the most efficient and most economical apparatus for eliminating evaporation.

Losses by evaporation benefit no one. If there is excessive evaporation on the lease before the pipe line takes the oil, the pipe-line company will have less evaporation because of its handling a less volatile oil, but the producer should not suffer a large volumetric loss and the refiner a large qualitative loss in order that the pipe-line company may have a smaller evaporation loss.

The chief evaporation losses must be eliminated by the producer, because they occur while the oil is on the lease. The expense and trouble of reducing these losses should be repaid either by a better price for a better quality of crude or by the producers saving the oil vapors and marketing them as gasoline.

PART III.—SCIENTIFIC DATA ON THE EVAPORATION OF PETROLEUM PRODUCTS.

VAPOR PRESSURE.

The vapor pressure of a liquid is the pressure that the vapor from the liquid will set up in a vacuum before evaporation ceases, or it is the partial pressure that the same liquid would set up in a closed vessel containing air. For the same liquid this pressure varies, rising with increase of temperature. Hence vapor pressure determines the proportion of gasoline vapor that a given volume of air will take up. The lighter the fraction distilled from a crude oil, the greater is its vapor pressure. It can not be said that all gasolines of higher Baumé gravity have higher vapor pressures, provided the gasolines are from different crudes, because gravity is not an exact criterion of the composition of gasolines. In general, however, it is true that the vapor pressures of gasolines vary with the Baumé gravity, especially if the gasolines are made from the same crude.

TABLE 26.—*Vapor pressure, in millimeters of mercury, of gasolines of different gravities and percentage of gasoline vapor for saturating air at different temperatures.*

Temperature.		73° B.		69° B.		64° B.		61° B.		56° B.		Water.	
		Vapor pressure.	Vapor for saturation.	Vapor pressure.	Vapor for saturation.	Vapor pressure.	Vapor for saturation.	Vapor pressure.	Vapor for saturation.	Vapor pressure.	Vapor for saturation.	Vapor pressure.	Vapor for saturation.
° F.	*° C.*	*Mm.*	*P. ct.*	*Mm.*	*P. ct.*	*Mm.*	*P. ct.*	*Mm.*	*P. ct.*	*Mm.*	*P. ct.*	*Mm.*	*P. ct.*
32	0	110	14.5	58	7.6	41	5.4	25	3.3	22	2.9	5	0.7
41	5	135	17.8	66	8.7	55	7.2	32	4.2	29	3.8	7	.9
50	10	162	21.3	82	10.8	62	8.2	40	5.3	34	4.5	9	1.2
59	15	194	25.5	100	13.2	74	9.7	52	6.8	38	5.0	13	1.7
68	20	235	30.9	121	15.9	88	11.6	64	8.4	42	5.5	17	2.2
77	25	279	36.7	148	19.5	106	14.0	77	10.1	47	6.2	24	3.2
86	30	337	44.3	177	23.3	129	17.0	93	12.2	55	7.2	32	4.2
95	35	397	52.3	215	28.3	157	20.7	113	14.9	66	8.7	42	5.5

Table 26, compiled from data published by Burrell and Boyd,[5] shows the vapor pressures of gasolines of different gravities and the percentage of gasoline vapor necessary to saturate air of different temperatures. The data apply only to the commercial gasolines used. Note that the vapor pressures of gasoline are much higher than those of water, which is one reason why gasoline evaporates so much more rapidly.

---

[5] Burrell, G. A., and Boyd, H. F., Quantity of gasoline necessary to produce explosive vapors in sewers: Tech. Paper 117, Bureau of Mines, 1916, 18 pp.

Figure 44 shows the percentage of gasoline necessary for saturation of air as the gravity of the gasoline varies. It is shown for temperatures ranging from 32° F. to 86° F. When tanks breathe, the percentage of gasoline vapor in the mixture forced from the tank has direct bearing on the volumetric loss through evaporation. If the breathing can be minimized, the evaporation from a tank will necessarily be lessened, for then the mixture of vapor and air under the roof rapidly becomes saturated and evaporation stops. When some of the mixture is forced out and pure air drawn in, the balance is disturbed; evaporation begins and continues until the mixture is again saturated with gasoline vapor.

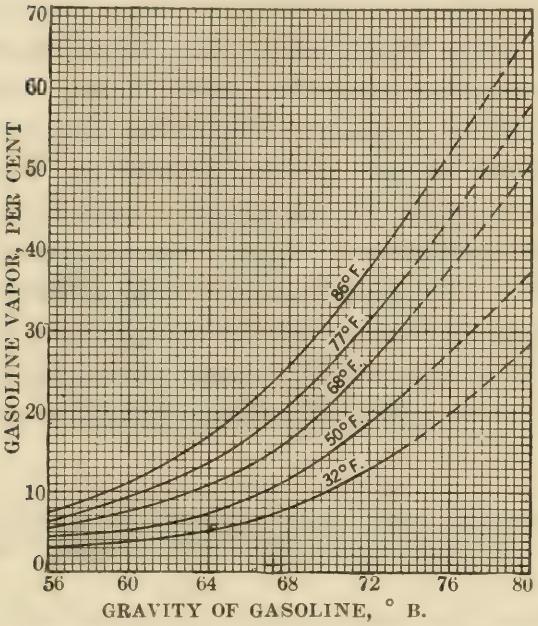


FIGURE 44.—Variation of percentage of gasoline vapor necessary for saturation of air at different temperatures as ° B. of gasoline varies.

LATENT HEAT OF EVAPORIZATION.

When a liquid evaporates, a large amount of heat is absorbed from the surroundings to supply the latent heat of evaporation of the liquid. Naturally, the greater the amount of heat necessary for this, the slower will be the rate of evaporation. A comparison of water and gasoline shows that the latent heat of vaporization of water is 970 B. t. u. per pound, whereas for gasoline it is about 135 B. t. u. per pound.[6] It is thus seen that only one-eighth as much heat would have to be supplied for vaporizing gasoline as for vaporizing water. Here is another reason why the light fractions of petroleum evaporate so rapidly. As evaporation implies the absorption of heat from the surrounding medium, its effect is to cause cooling. The less the cooling, the more rapid will be the evaporation.

---

[6] Landolt, Hans, and Börnstein, Richard, Physikalisch-chemische Tabellen: Berlin, 1894, p. 350.

CONVECTION CURRENTS IN OIL.

Convection currents in tanks of oil result from two principal causes. The first is the change in temperature of the oil at any point. If this point is below the surface and the temperature there increases, the warmer oil rises. At unprotected steel tanks, the sun beating on the steel heats it rapidly. This heat is transmitted by conduction through the steel to the film of oil inside, which immediately starts to rise.

The second reason for convection currents is evaporation of the lighter fractions at the surface and the consequent lowering of the gravity of the oil there. This oil, becoming heavier, begins to sink and its place is taken by the lighter oil just below. Calculation shows that 1 per cent evaporation of light gasoline from crude has approximately the same effect on the specific gravity of the crude as a 5 to 8° F. change in temperature. Ordinarily, the temperature in a large tank decreases toward the bottom, tending to create a condition of stability. Were it not for the heating or cooling of the sides of the steel tank, the movement of the oil would depend upon the evaporation at the surface, and the convection currents would tend to be directly vertical.

VISCOSITY.

Viscosity decreases the movement of lighter oil from the bottom to the top, and, therefore, has some effect on the rate of evaporation of a crude. It is believed, however, that the viscosities of the light Mid-Continent crudes considered in this investigation, although not uniform, do not differ enough to affect their rates of evaporation materially. In very heavy oils of small gasoline content, viscosity would tend to retard the rate of evaporation much more than in light, less viscous oils.

CONDITIONS TO BE ATTAINED TO DECREASE EVAPORATION.

Crude oil exposed to the air continues to evaporate for a long time. When the mixture of air and vapor at the surface of the oil is nearly pure air, as it is when wind blows across the surface freely, the rate of evaporation is most rapid. As the proportion of vapor in the vapor-air mixture above the oil increases, the rate of evaporation decreases. When the mixture finally contains as much of the vapor as it can possibly hold under given temperature and pressure conditions, that is, when it is saturated, evaporation ceases. The oil in a tank with a gas-tight cover evaporates until the air under the roof is saturated. If no fresh air enters this mixture of air and vapor, evaporation ceases. In practice, however, temperature changes cause expansion or contraction of gas under the roof, and the tank "breathes."

Evidently the temperature of the gas under the roof should be kept as nearly constant as possible. To practically eliminate evaporation, therefore, it is necessary to confine the space above the oil in a tank and to keep that space at a constant temperature, or a variable pressure, then the only evaporation loss will be that necessary to saturate the space above the oil.

To accomplish this, tank roofs should be absolutely gas-tight, with automatic pressure valves. Some tanks containing very volatile products should also be protected from the sun in some manner.

CHANGES IN OIL AND IN THE PART LOST BY EVAPORATION.

A number of results follow the evaporation of crude oil. First the gravity of the crude becomes heavier with the escape of the lighter fractions. Second, as evaporation continues the fraction that is actually being evaporated becomes heavier and heavier. Third, the boiling point of the evaporating fraction rises as the gravity becomes heavier. Fourth, the average specific gravity of the fractions lost by evaporation increases.

Data concerning the above effects of evaporation on three standard types and one special type of tanks—250 and 500 barrel unprotected steel tanks, 500-barrel jacketed steel tanks, and 1,600-barrel housed wood tanks—in summer, with the gravity of oil ranging from 35 to 37° B., may be assembled in four groups, according to the effect on degrees Baumé of crude, the effect on the degrees Baumé of the fraction evaporating, the effect on the boiling point of the fraction evaporating, and the effect on the degrees Baumé of the portion lost. Note that different effects are shown for the same group of tanks. A study of the difference in effect between one kind of tank and another will give the relative values of each type in eliminating evaporation.

Moreover, it is desired to indicate the destructive effect of evaporation on the gasoline content of crude.

SOURCE OF DATA.

The results under the heading have been taken from the field experiments shown in Part III. Data enough to show these results were taken on every test. To print all of them in this bulletin would require too much space, consequently they have been classified as shown above.

EFFECT ON GRAVITY OF CRUDE.

As oil evaporates, that is, as the lighter fractions escape, its Baumé gravity necessarily becomes heavier. Data on this increase for several oils under various conditions of storage, presented in figure 45, show that the oil stored in 250-barrel unprotected steel tanks suffers the greatest loss in Baumé gravity, whereas that stored in a 500-barrel jacketed steel tank suffers the least. These data bear out the relative volumetric losses shown for these classes of storage in Part II of this report.

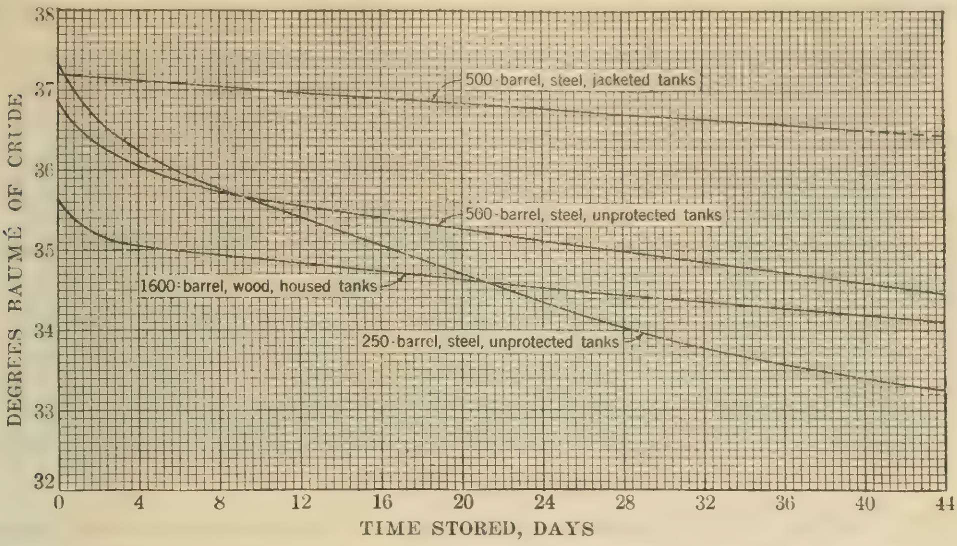


FIGURE 45.—Drop in °B. gravity of crude stored in different kinds of tanks—summer.

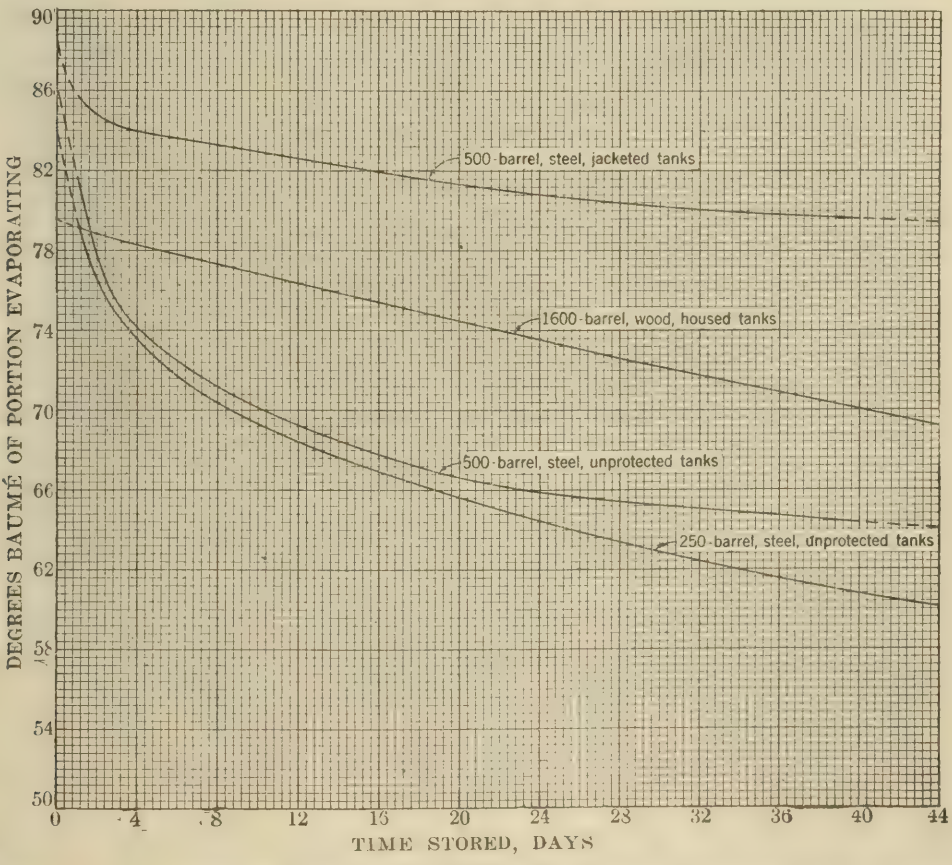


FIGURE 46.—°B, gravity of fraction evaporating for tanks of various kinds—summer.

GRAVITY OF FRACTION EVAPORATING.

Figure 46 shows the degrees Baumé of the fraction that is evaporating for crudes under various conditions of storage. "Fraction" does not refer to a pure hydrocarbon, but to a mixture of hydrocarbons within comparatively narrow limits. Here again it is seen that heavier fractions were in process of evaporating from the 250-barrel steel tank than from the 500-barrel jacketed steel tank. These

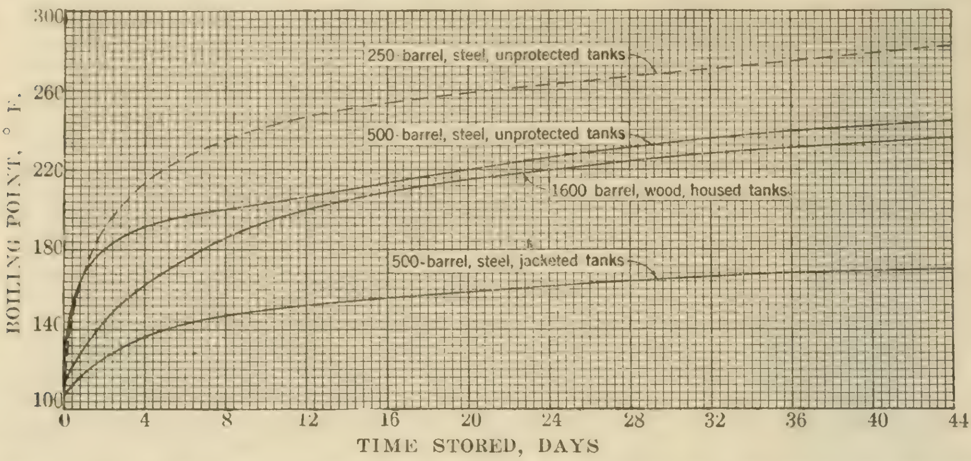


FIGURE 47.—Boiling points of fractions evaporating from tanks of various kinds—summer.

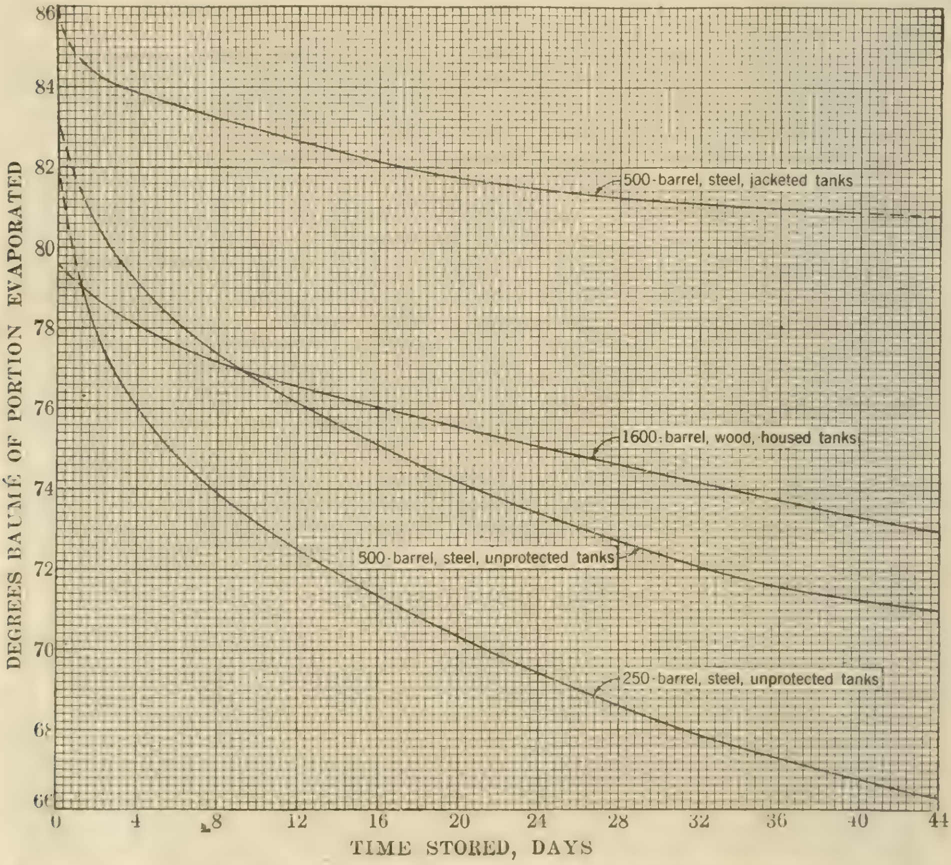


FIGURE 48.—°B. gravity of the portion which has evaporated from tanks of various kinds—summer.

fractions in the 250-barrel tank were not only heavier but the volume evaporated was greater, which is added proof of the economy of protecting tanks against air circulation.

BOILING POINT OF FRACTION EVAPORATING.

The boiling points of the fractions evaporating are shown in figure 47 for the same conditions of storage that have been utilized as noted above. This was determined in a manner similar to the method for finding the degrees Baumé of the fraction evaporating. The boiling point of the fraction evaporating from the 250-barrel exposed steel tank is very much higher than the boiling point of the fraction evaporating from the 500-barrel jacketed steel tank, with the other types falling in between.

GRAVITY OF PORTION EVAPORATED.

As evaporation continues the gravity of the total part that has been lost from the start of the test becomes heavier, as shown in figure 48. It is seen that under the same conditions of storage, as previously described, in 39 days a 250-barrel exposed steel tank lost gasoline having an average gravity of 67° B. During the same period a 500-barrel jacketed steel tank lost gasoline of 81° B.

LABORATORY EVAPORATION TESTS.

COMPARISON OF RATES OF EVAPORATION OF PETROLEUM AND PURE GASOLINE FROM THE SAME PETROLEUM.

Laboratory tests were made to determine this relation. The purpose was to determine how much slower gasoline will evaporate in the crude in its natural state than distilled. Fractions were taken at 10 per cent intervals until the third 10 per cent cut was completed. Each of these cuts was exposed to the air under exactly the same conditions and at the same time. Enough of the original crude to give the volume of each of the above cuts was also exposed in a similar manner, and the evaporation of each was noted periodically. The results of these tests are shown in figures 49, 50, 51, and 52 and in Table 27.

The rate of evaporation of the crude is compared with the rate of evaporation of the first 10 per cent distilled, the ratio of the gasoline rate to the crude rate ranging from 1.61 to 2.23 and averaging 1.91. The very light gasoline evaporated practically only twice as fast when free as when in the crude, or, conversely, the gasoline when in the crude evaporated one-half as fast as when free.

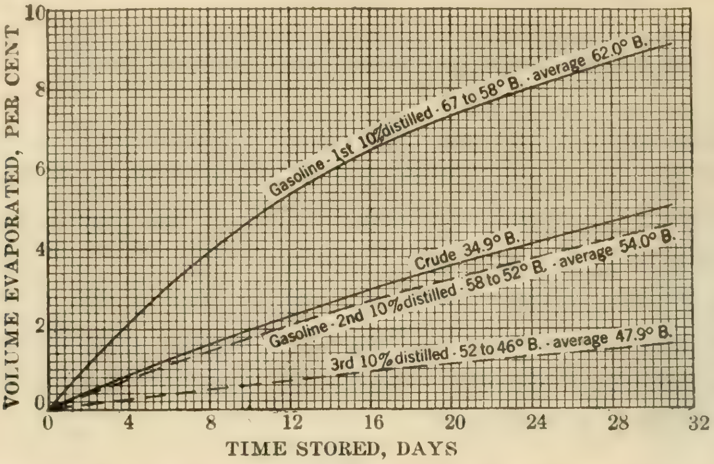


Figure 49.—Comparison of evaporation of El Dorado, Kansas, crude and the gasoline and kerosene cuts from that crude exposed in pure state. First 10 per cent, second 10 per cent, and third 10 per cent distilled and crude exposed separately. All evaporative conditions identical.

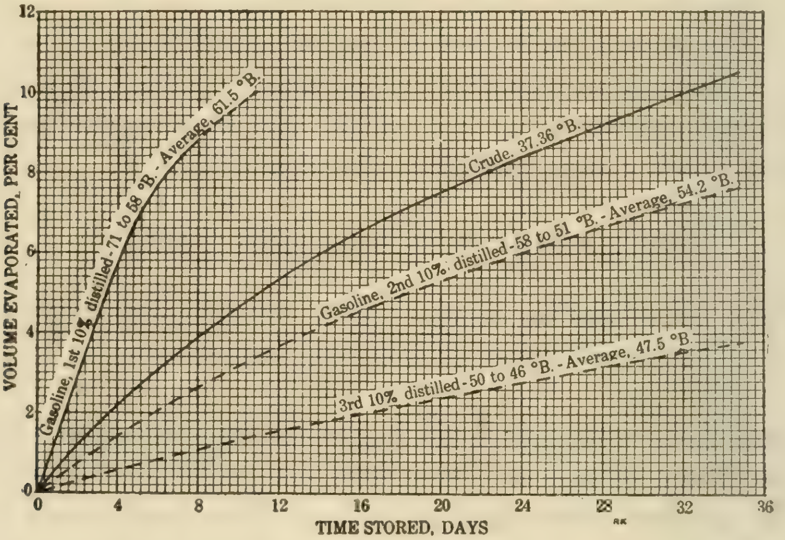


Figure 50.—Comparison of evaporation of crude from Ranger, Tex., field and the gasoline and kerosene cuts from that crude exposed in pure state. First 10 per cent, second 10 per cent, and third 10 per cent distilled and crude exposed separately. All evaporative conditions identical.

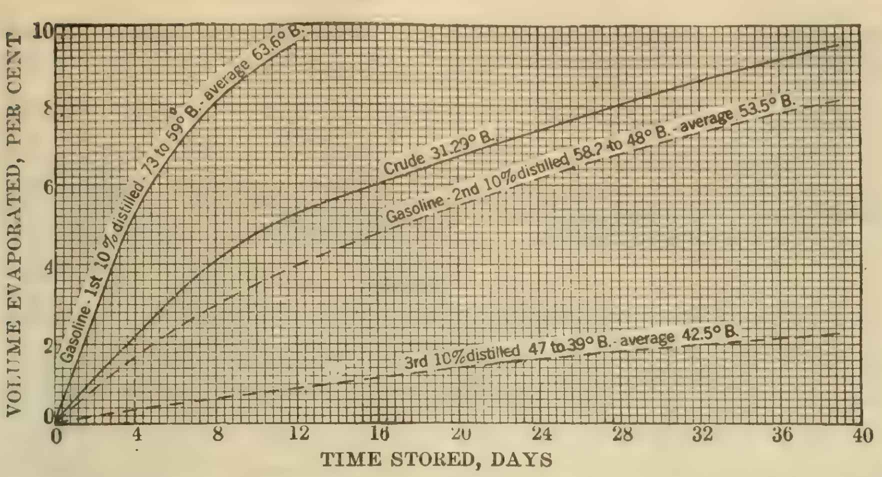


FIGURE 51.—Comparison of evaporation of crude from Coalinga, Calif., field and the gasoline and kerosene cuts from that crude exposed in pure state. First 10 per cent, second 10 per cent, and third 10 per cent distilled and crude exposed separately. All evaporative conditions identical.

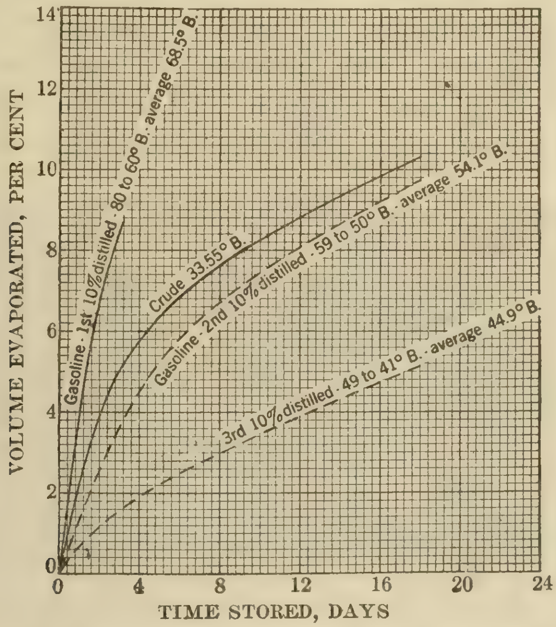


FIGURE 52.—Comparison of evaporation of crude from Coalinga, Calif., field and the gasoline and kerosene cuts from that crude exposed in pure state. First 10 per cent, second 10 per cent, and third 10 per cent distilled and crude exposed separately. All evaporative conditions identical.

TABLE 27.—*Results of tests to determine the comparative rates of evaporation of gasoline exposed in the pure state and as it exists naturally in the crude.*

Experiment No.	Source of crude.	Gravity.			Ratio of gasoline rate to crude rate.	Number of days.
		First 10 per cent of gasoline distilled.		Crude.		
		Average.	Range.			
		°*B.*	°*B.*	°*B.*		
1	Texas	67.3	76 to 63	40.0	2.04	6
2	do	62	67 to 58	40.1	1.97	17
3	do	61.5	71 to 58	37.4	2.23	8
4	California	68.5	80 to 60	33.6	1.61	3
5	do	63.6	73 to 59	31.6	1.82	12
6	Kansas	62	67 to 58	34.9	1.79	31
Average		64.1	72 to 59	36.2	1.91	13

This ratio holds for gasoline above 60° B., such as tested. Here is a striking fact. If handlers of crude oil having a high gasoline content or containing any light gasoline realized that the loss from evaporation in handling that crude was one-half as great as the loss in handling the light gasoline in a free state they would see clearly the necessity of taking better care of their crude. A comparison of the rates of evaporation of the crudes appears on a subsequent page.

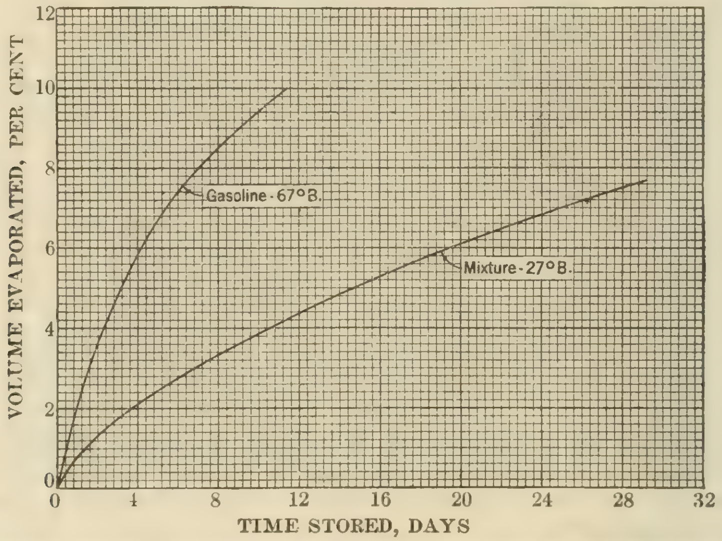


FIGURE 53.—Comparison of evaporation of pure gasoline and the same gasoline when blended with heavy lubricating oil in the ratio of 10 per cent gasoline to 90 per cent lubricating oil. All evaporative conditions are identical.

EVAPORATION OF GASOLINE EXPOSED IN THE PURE STATE AND AFTER BLENDING WITH HEAVY LUBRICATING OIL.

The first 10 per cent distilled from a crude was mixed with a heavy lubricating oil of 22° B—the latter representing 90 per cent of the mixture—and was stirred thoroughly. This mixture was exposed in exactly the same manner as the pure gasoline. A number of such experiments were made with gasolines from different crudes. The results of these tests are shown in figure 53, which comprises composite curves for all the tests. In Table 28 the rate of evaporation of the mixture has been compared to the rate of evaporation of the pure gasoline.

Note in this table that the lubricating oil was heavier and in consequence had a higher viscosity than the crudes used in previous experiments. Note also that the ratio column of Table 28 is larger than that of Table 27. The result is that the gasoline in a mixture of high viscosity evaporates more slowly than similar gasoline in a mixture of lower viscosity. This same point is brought out in figure 54 by the separation of the two curves along the ordinates.

Table 28.—*Results of tests comparing the rate of evaporation of gasoline exposed in pure state and blended with lubricating oil.*

Experiment No.	Source of crude.	Gravity.			Mixture.		Ratio of gasoline rate to mixture rate of evaporation.
		First 10 per cent of gasoline distilled.		Lubricating oil.	Lubricating oil.	Gasoline.	
		Average.	Range.				
		°B.	*°B.*	*°B.*	*Per cent.*	*Per cent.*	
1	California	70.1	80 to 61	22	90	10	2.3
2	do	53.4	59 to 49	22	90	10	2.8
3	Texas	65.1	77 to 60	22	90	10	2.6
Average		62.9	72 to 53	22	90	10	2.57

RELATION OF THE GRAVITY OF GASOLINE TO THE RATE OF EVAPORATION OF THE ORIGINAL CRUDE.

In figure 54 one interpretation of results of the two preceding classes of experiments has been plotted.

In this figure the points from the "crude–gasoline" experiments show that the lighter the gravity of the gasoline, the nearer the rate of evaporation of the crude approaches that of the gasoline. In the "mixture–gasoline" experiments in the same figure, the same effect is noticed. The conclusion is that the more volatile the constituents of a crude oil, the more nearly will that crude evaporate at the rate of those constituents when exposed in a free state. In other words, the viscosity of the crude medium and the intimate mixing of the evaporating fractions with the whole volume of the crude reduce the rate of evaporation of the volatile fractions in the crude less and less as these fractions become more and more volatile.

EFFECT OF BLENDING LIGHT GASOLINE WITH HEAVIER PRODUCTS.

The first 10 per cent distilled from a crude was blended with heavier gasoline in one test and with mineral seal oil in another, and the rates of evaporation of the blends were compared with the rate of the pure gasoline, all evaporative conditions being the same. The results of these tests appear in figures 55 and 56. In both tests the pure gasoline evaporated little faster than when it was blended.

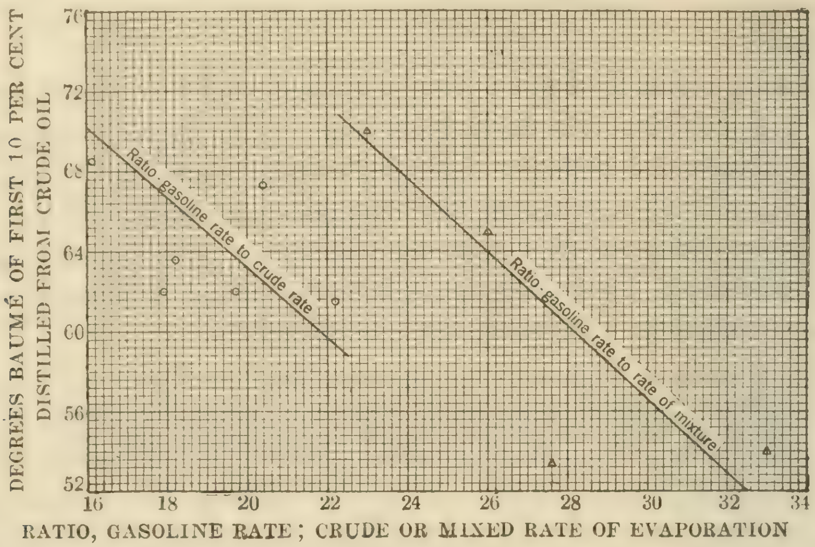


FIGURE 54.—Relation between the °B. of gasoline in a crude oil and the ratio of the rates of evaporation of (1) crude oil and the first 10 per cent of gasoline distilled therefrom; (2) gasoline and a blend of the same gasoline with heavy lubricating oil—10 per cent gasoline to 90 per cent lubricating oil.

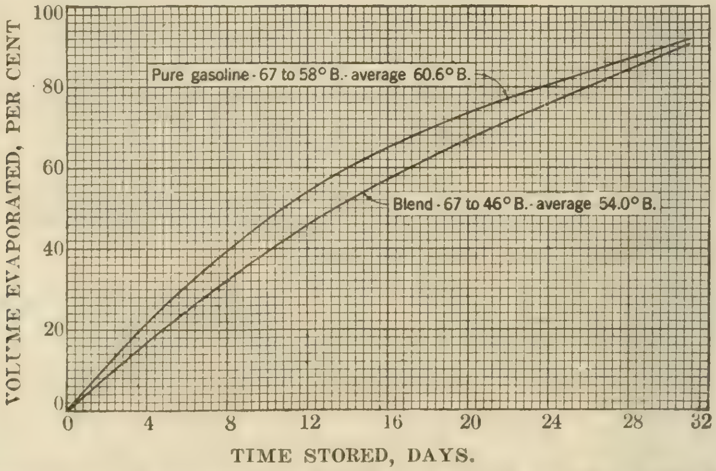


FIGURE 55.—Comparison of evaporation of 61° B. gasoline and the same gasoline blended with heavier cuts in the ratio of 33⅓ per cent of 61° B. gasoline and 33⅓ per cent of 53.6° B. and 33⅓ per cent of 47.9° B. cuts. All evaporative conditions are identical.

In Bulletin 88,[7] figures 12, 13, and 14 (see pp. 87–89), the authors show the results of experiments on "compression" natural-gas gasoline blended with naphthas which very closely resemble the results printed in this report. The gasolines used in the tests described in this bulletin are of the same quality as gasoline from the refinery. Gasolines obtained from natural gas contain much permanent gas dissolved in them.

---

[7] Burrell, G. A., Seibert, F. M., and Oberfell, G. G., The condensation of gasoline from natural gas: Bull. 8, Bureau of Mines, 1915, 106 pp.

RATE OF EVAPORATION OF GASOLINES DERIVED FROM CRUDES FROM DIFFERENT SOURCES.

The gravity of a liquid does not necessarily affect its rate of evaporation, the latter depending upon the boiling point or vapor pressure. In commercial gasolines, many of which are made by blending heavy fractions with very light casing-head fractions, it is well known that the gravity of the mixtures bears little relation to the boiling range, and hence the rates of evaporation. However, straight-run gasolines obtained by making narrow cuts from the crude have different gravities for the same boiling point, or, conversely, different boiling points for the same gravity, when the crudes come from different parts of the United States. Especially is this noted among Pennsylvania, Kansas, and California gasolines. A California straight-run gasoline has a much lower boiling range than a straight-run Pennsylvania gasoline of the same gravity.

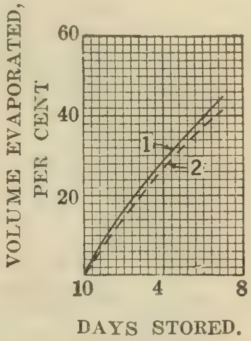


FIGURE 56.—A comparison of evaporation of gasoline of 66.9° B. to that of a blend of it with mineral seal oil in the ratio of 50 per cent mineral seal oil to 50 per cent gasoline. All evaporative conditions identical.

Therefore a third class of experiments was designed to compare the rates of evaporation of gasolines of approximately the same degrees Baumé, but derived from crudes of El Dorado, Kans.; Ranger, Tex.; and Coalinga, Calif. The results of these tests are shown in figures 57 and 58. Figure 57 compares the California and Texas and figure 58 the Kansas and Texas gasolines. These figures show that straight-run gasolines of nearly the same gravity and range of gravity, whether derived from the Texas or California crudes used, evaporate at nearly the same rate. The gravity of the California crude was 32° B., that of the Texas 40° B.

An important feature is brought out in figure 58. A straight-run gasoline from El Dorado, Kans., crude evaporates considerably slower (nearly one-half) than that from Ranger, Tex., crude, although both gasolines have practically the same average gravity and the same range of gravities of successive fractions. The gravities of the two crudes were 36 and 40° B., respectively.

In 1916 Rittman, Jacobs, and Dean tested commercial gasolines from many fields in the United States. In one test they subjected equal volumes of each sample to identical evaporative conditions and recorded the percentage of the original volume which was lost.[8] Figure 59 shows that the California gasolines of the same gravity evaporate approximately twice as fast as those from the other fields, thus corroborating the work of the author and adding the Pennsylvania gasolines to the "slow" group. Some of the Pennsylvania gasolines contained very light casing-head gasoline, otherwise the

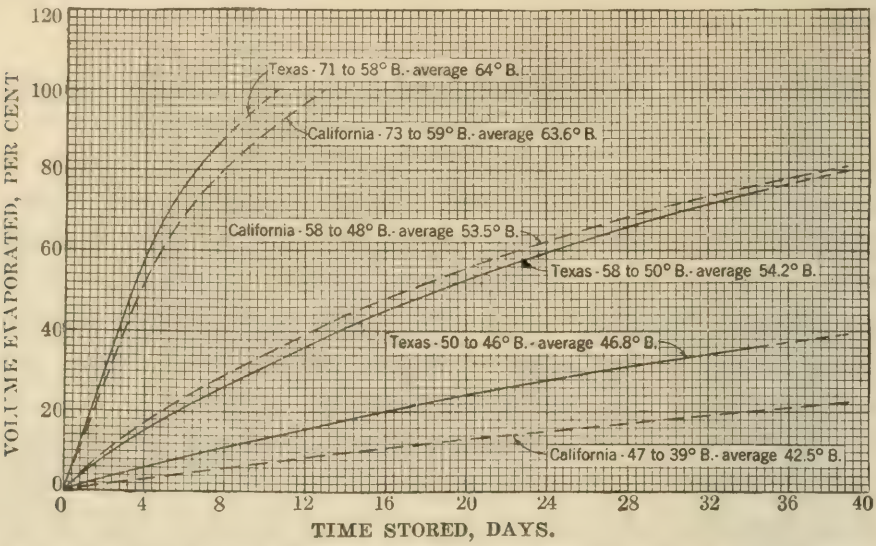


FIGURE 57.—Comparison of evaporation of gasolines from Ranger, Tex., and Coalinga, Calif., light crudes. All evaporative conditions identical.

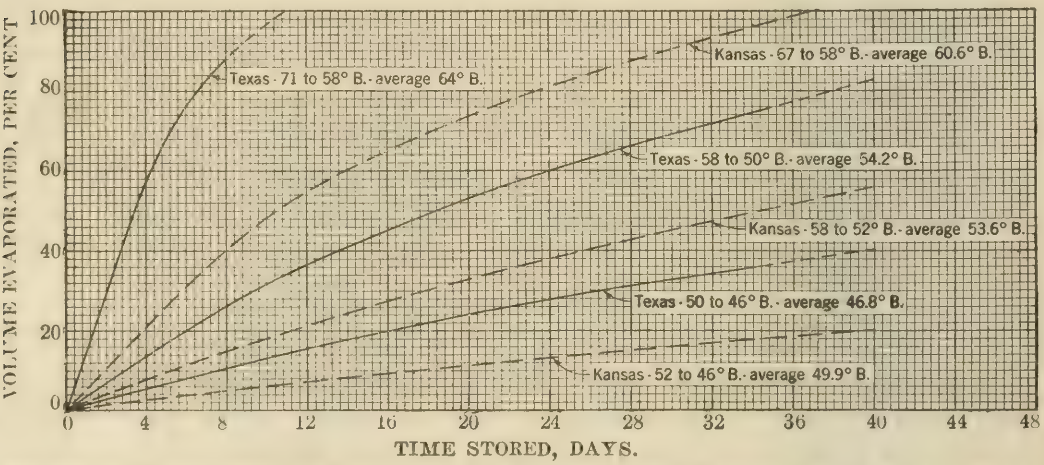


FIGURE 58.—Comparison of evaporation of gasolines from Ranger, Tex., and El Dorado, Kans., crudes. All evaporative conditions identical.

---

[8] Rittmann, W. F., Jacobs, W. A., and Dean, E W., Physical and chemical properties of gasolines sold throughout the United States during the calendar year 1915: Tech. Paper 163, Bureau of Mines, 1916, p. 16.

Pennsylvania would be slower than the Kansas gasolines. Each curve represents the average result of all the tests made on the gasolines from that field.

CONCLUSIONS FROM LABORATORY TESTS.

The general conclusions from all these laboratory experiments are as follows: First, under the same conditions of evaporation, gasoline derived from light crude (not casing-head) will evaporate one-half as rapidly when in the crude as when in the pure state after distillation. Second, blending a gasoline with a very heavy viscous high-flash oil will decrease its rate of evaporation very much—by nearly two-thirds in tests in this report. Third, blending a gasoline that contains practically no "wild" fractions (that is, dissolved permanent gases) with heavy gasoline or with oils such as mineral seal oil will not decrease materially its rate of evaporation. Fourth, the source of the crude will serve to indicate the rate of evaporation of the derived gasoline as compared with that of gasoline from another source, provided fractions evaporating have the same gravity. Fifth, the gravity of crudes from widely separated fields is not a criterion of their relative rates of evaporation. Of these five conclusions the first is the most important.

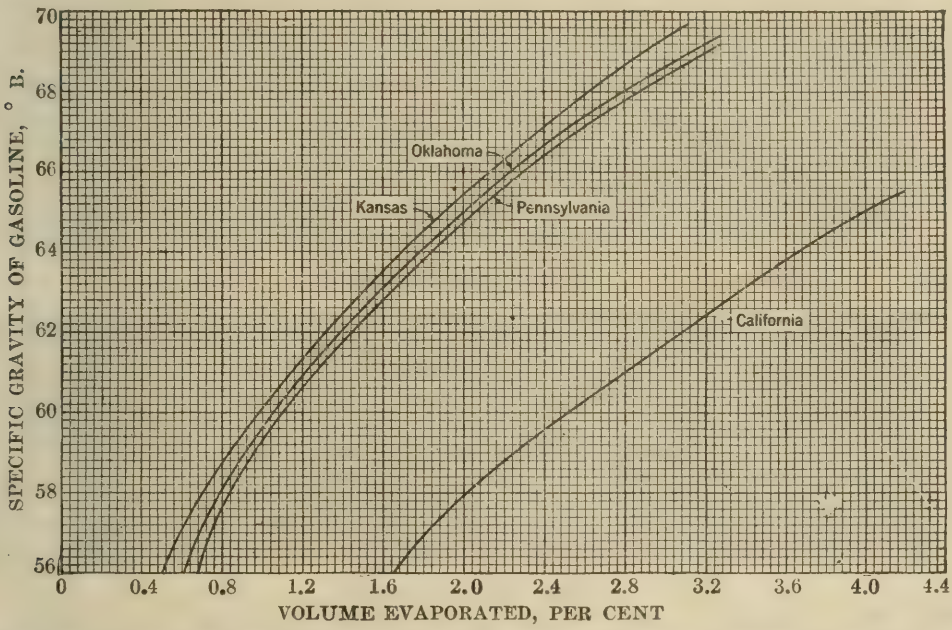


FIGURE 59.—Relative rates of evaporation of gasolines from different fields. All evaporative conditions are identical.

RATE OF EVAPORATION OF CRUDES FROM DIFFERENT SOURCES.

Whether a crude from Kansas evaporated at the same rate as one from Texas or California (all light crudes) was investigated in the laboratory, the rate of evaporation being studied carefully in conjunction with the "gravity–per cent distilled" curves of the three kinds of oil. The results shown in figures 60 and 61 represent the composite of a number of experiments on each oil. Naturally, it was very difficult to obtain from these widely separated fields three oils that would give practically the same "gravity–per cent distilled" curves.

The points of similarity between the crudes were: First, all were comparatively light, the heaviest being 31.7° B., the lightest, 37.4° B.; second, they all had a large percentage of gasoline—between 25 and 33 per cent; and third, the average gravity of the fraction that evaporated from each crude during the period of observation was practically the same. With these points of similarity, the purpose was to determine the difference in their rates of evaporation under identical evaporative conditions.

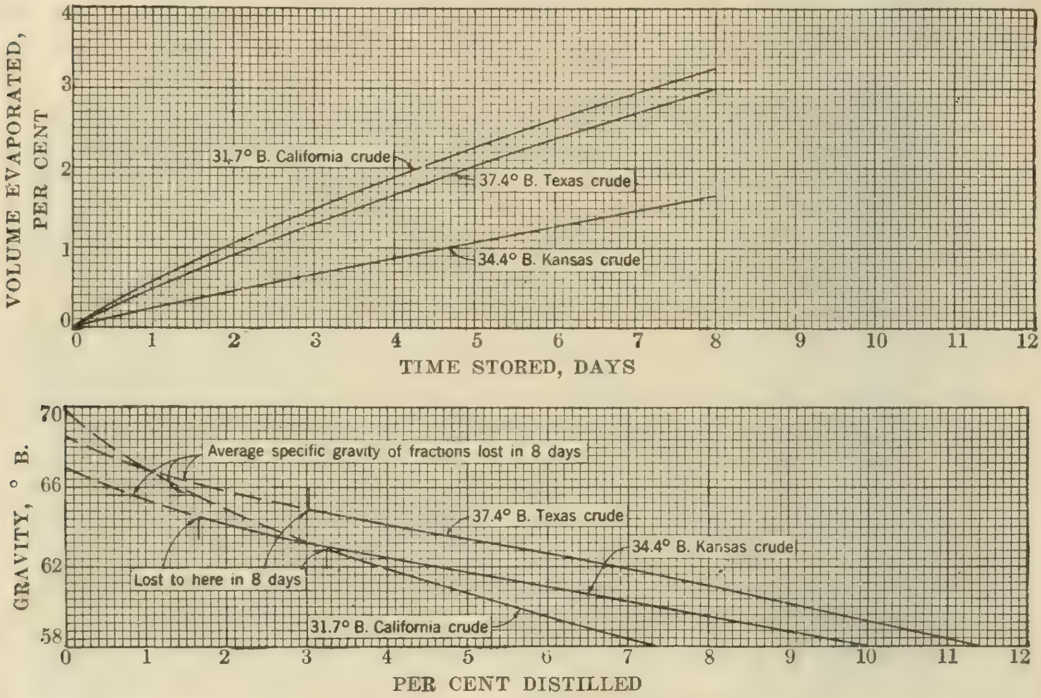


Figure 60.—Comparison of the rates of evaporation of El Dorado, Kans., Ranger, Tex., and Coalinga, Calif., crudes with distillation curves of each. Dashed parts of the latter show the respective portions lost in eight days.

How nearly identical were the distillation curves will be seen by observing those in figure 60.

The dashed part of the distillation curves shows the gravity of the portion of each oil evaporating during the period of eight days, and is the only part to be considered for these tests. Note that the gravity of the fraction evaporating from the California crude ranges from 69.9 to 62.9° B., and the evaporation curve for this oil indicates that its rate does not vary greatly between these gravities. The same conclusions may be drawn regarding the Texas and Kansas oils.

Compare first the Kansas and the California oils. The average gravity of the fraction lost by each during the eight days was 65.6° B. This fact and the fact that even between the gravity limits shown each crude has a nearly constant rate of evaporation, indicate that as far as concerns the rate of evaporation (from the natural crude) it is as if fractions of identical gravity have been compared. (Theoretically, this assumption is not absolutely true, but for practical purposes it is sufficiently close.) In eight days the California oil lost 3.25 per cent of its original volume and the Kansas oil lost 1.67 per cent. The conclusion is, then, that fractions from California crude evaporated 1.95 times as fast as fractions of the same gravity from Kansas crude. Similar observations taken within much narrower limits, or to the differentials, show approximately the same relation. It is reasonable to conclude, therefore, that the gravity of gasolines evaporating from crudes is not, by itself, a sure basis for comparing the evaporation loss from the crudes. This conclusion increases the complexity of the evaporation problem.

The crudes under consideration are as follows: Kansas crude of 34.4° B., from the El Dorado pool; Texas crude of 37.4° B., from the pools near Ranger; and California crude of 31.7° B., from the fields near Coalinga.

Compare the Texas and the Kansas crudes. The Texas crudes evaporated 1.8 times as fast as the Kansas crudes when fractions of practically the same average gravity (66.4 and 65.6° B.) were evaporating.

Compare the Texas and California crudes. They lose at about the same rate when fractions of practically the same gravity are evaporating, the California crude having a slightly faster rate.

The heaviest oil (California crude of 31.7° B.) evaporated faster than either the 37.4° B. Texas or the 34.4° B. Kansas crude, and the Texas crude of 37.4° B. evaporated much more rapidly than the Kansas crude of 34.4° B. Here again is proof that the gravity alone of an oil is not a criterion for estimating the rate of evaporation.

COMPARISON OF MID-CONTINENT OILS BY DISTILLATIONS.

Distillation tests afford a good basis for estimating the probable evaporation loss of two or more oils under like conditions. Figure 61 gives this information for Kansas, Oklahoma, and Texas oils.

When comparing these crudes, assume that evaporation starts with the 76° B. constituent and that the portions of the curve above that point are eliminated. If the rates of evaporation of all four oils between 76 and 72° B. are all nearly the same, this rate will hold for the Kansas 34.1° B. oil while 0.6 per cent of its original volume evaporates. This result is attained by subtracting the per cents at which the "gravity" curve of this oil cuts the ordinates 72 and 76° B., or 0.7 to 0.1=0.6 per cent. Similarly, 36 and 36.8° B. Kansas oils will have this rate of evaporation for 1 per cent and 1.4 per cent of their volumes, respectively. Texas and Garber oils will have this rate for 0.6 per cent and 2.3 per cent of their volumes, respectively. This figure, 2.3 per cent, shows why Garber oil will lose more than the others, because while it evaporates only at the rate of the others, this rate of evaporation continues longer and results in the loss of a larger percentage.

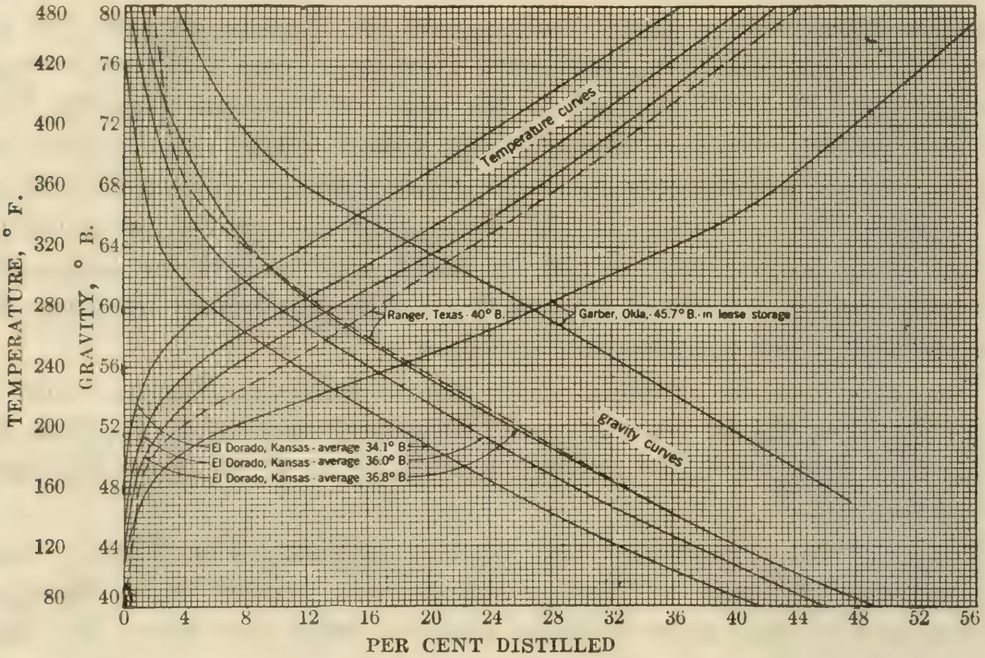


FIGURE 61.—Comparison of crude oils from El Dorado, Kans., Garber, Okla., and Ranger, Tex., by distillations.

PROPORTION OF GAS DISSOLVED IN OIL.

Two experiments were made to determine what proportion of the evaporation might be attributable to gas dissolved in the oil.

Any vapors that did not condense in the regular distillation apparatus were passed through absorption oil, and the portion not absorbed, "permanent" gas, was measured. The results are shown in Table 29. One sample represented the average oil of the Mid-Continent, having a gravity of 35.7° B.; the other was direct from a well in the Garber field, with a gravity of 48.2° B. It is a striking fact that the latter had less dissolved gas than the former. Evidently the enormous losses from evaporation are not "wild" gas, but largely a recoverable product.

TABLE 29.—*Results of tests to determine the amount of gas in oil that is nonrecoverable by ordinary condensation.*

	Oil of 35.7° B.[a], El-Dorado, Kans.		Oil of 48.2° B. (unusually light) Garber, Okla.	
	Mineral seal.[b]	Gravity.	Mineral seal.[c]	Gravity.
	c. c.	°*B.*	*c. c.*	°*B.*
Before	200	36.9	200	36.8
After	203	36.9	[d]205	36.9

[a] About the average gravity of the samples tested.

[b] Gas not absorbed by mineral seal oil at atmospheric pressure=0.04 cu. ft.=3.4 c. c. liquid=0.23 per cent of sample distilled.

[c] Gas not absorbed by mineral seal oil at atmospheric pressure=0.02 cu. ft.=1.7 c. c. liquid=0.11 per cent of sample distilled. The gas not absorbed is regarded as permanent gas.

[d] The increase in volume of the mineral seal oil represents products that were not condensed but could be recovered by the absorption medium.

GENERAL CONCLUSIONS.

The principal conclusions drawn from the facts presented in this bulletin are as follows:

1. Evaporation during storage and handling causes one of the largest losses of crude petroleum between the well and the refinery. (See p. 86.)
2. From two-thirds to four-fifths of the evaporation loss may be eliminated by protecting oil from free contact with air. This protection will pay for itself in a short time.
3. The percentage of the original value lost by evaporation is two or three times the percentage of the original volume lost, because the fraction that escapes from the crude oil is the best gasoline and its value per unit of volume is two or three times that of the crude.
4. The maximum prevention of evaporation involves keeping the mixture of air and vapor above the oil at rest and as near a constant temperature, whether high or low, as possible. For example, if the mixture of air and vapor above the oil does not move very little more evaporation will take place at 115° F. than at 32° F., because the mixture will soon become saturated and then evaporation will cease. (See p. 91.)
5. The major part of evaporation loss, when the most valuable products escape, takes place on the lease when the oil is still fresh.
6. Oil is liable to evaporation loss, even after it leaves the lease.
7. Dehydration in open steaming tanks is the most flagrant example of the neglect of evaporation losses. Such plants should be made air-tight with valves for regulating pressures. (See p. 40.)
8. Overshot connections should never be used for filling a tank.
9. Even in winter, when atmospheric temperatures are low, oil in exposed lease tanks will lose more than one-half what it would lose during similar storage in summer.

10. Oil at the surface of 55,000-barrel tanks, where evaporation takes place, is subjected during a part of the day to temperatures much higher than the average temperature of all the oil in the tank. In summer these surface temperatures rise above 100° F. Evidently in such storage the loss by evaporation must be large. (See p. 76.)

11. For one who handles crude, evaporation is almost as insistent a problem as it is for the refiner who handles the gasoline obtained from this crude, because gasoline in the natural crude will evaporate approximately one-half as rapidly as it will after being distilled and stored as pure gasoline. (See p. 98.)

12. Light crude oil from the Ranger, Tex., fields evaporates about as rapidly as pure gasoline derived from El Dorado, Kans., crude, provided the gravity of the fraction evaporating is the same. This means that the evaporation problem of the producer or the operator of a pipe line handling the Texas crude is as important as that of the refiner handling the Kansas gasolines. (See p. 101.)

13. The evaporation problem of those who handle Ranger, Tex., or Coalinga, Calif., light crude, is twice as insistent as the problem of those who handle El Dorado, Kans., crudes.

14. The more volatile the gasoline contained in a crude, the more nearly will the rate of evaporation of the crude approach the rate of evaporation of the gasoline (stored in the pure state) distilled from the crude (see p. 99), evaporating conditions in both cases being the same.

15. The increasing demand for crude oil and gasoline is making this problem more and more insistent. In future it may be considered as illegal to waste oil brought to the surface, as it is now considered illegal to waste it underground.

16. So many conditions vary the rate of evaporation that to cover them all would require an almost unlimited amount of work. Each operator of a lease or pipe line should attack and solve his own problem.

PUBLICATIONS ON OIL FIELD TECHNOLOGY.

A limited supply of the following publications of the Bureau of Mines has been printed and is available for free distribution until the edition is exhausted. Requests for all publications can not be granted, and to insure equitable distribution applicants are requested to limit their selection to publications that may be of especial interest to them. Requests for publications should be addressed to the Director, Bureau of Mines.

The Bureau of Mines issues a list showing all its publications available for free distribution as well as those obtainable only from the Superintendent of Documents, Government Printing Office, on payment of the price of printing. Interested persons should apply to the Director, Bureau of Mines, for a copy of the latest list.

PUBLICATIONS AVAILABLE FOR FREE DISTRIBUTION.

BULLETIN 170. Extinguishing and preventing oil and gas fires, by C. P. Bowie. 1918. 44 pp., 19 pls., 4 figs.

BULLETIN 175. Experiment stations of the Bureau of Mines, by Van. H. Manning. 1919. 160 pp., 29 pls., 2 figs.

BULLETIN 201. Prospecting and testing oil, gas, and water-bearing strata, by R. E. Collom. 1922. In press.

BULLETIN 216. Bibliography of petroleum and allied substances, 1919–20, by E. H. Burroughs. In press.

TECHNICAL PAPER 38. Wastes in the production and utilization of natural gas, and methods for their prevention, by Ralph Arnold and F. G. Clapp. 1913. 29 pp.

TECHNICAL PAPER 42. The prevention of waste of oil and gas from flowing wells in California, with a discussion of special methods used by J. A. Pollard, by Ralph Arnold and V. R. Garfias. 1913. 15 pp., 2 pls., 4 figs.

TECHNICAL PAPER 45. Waste of oil and gas in the Mid-Continent fields, by R. S. Blatchley. 1914. 54 pp., 2 pls., 15 figs.

TECHNICAL PAPER 66. Mud-laden fluid applied to well drilling, by J. A. Pollard and A. G. Heggem. 1914. 21 pp., 12 figs.

TECHNICAL PAPER 68. Drilling wells in Oklahoma by the mud-laden fluid method, by A. G. Heggem and J. A. Pollard. 1914. 27 pp., 5 figs.

TECHNICAL PAPER 209. Traps for saving gas at oil wells, by W. R. Hamilton. 1919. 34 pp., 3 pls., 16 figs.

TECHNICAL PAPER 232. Application of the absorption process to recover gasoline from residual gases of compression plants, by W. P. Dykema and Roy O. Neal. 1920. 43 pp., 6 pls., 10 figs.

TECHNICAL PAPER 247. Perforated casing and screen pipe in oil wells, by E. W. Wagy. 1920. 48 pp., 6 pls., 12 figs.

TECHNICAL PAPER 261. Oil camp sanitation, by C. P. Bowie. 1921. 31 pp., 3 pls., 4 figs.

PUBLICATIONS THAT MAY BE OBTAINED ONLY THROUGH THE SUPERINTENDENT OF DOCUMENTS.

Bulletin 134. The use of mud-laden fluid in oil and gas wells, by J. O. Lewis and W. F. McMurray. 1916. 86 pp., 3 pls., 18 figs. 15 cents.

Bulletin 148. Methods of increasing the recovery of oil from wells, by J. O. Lewis. 1917. 128 pp., 4 pls., 32 figs. 15 cents.

Bulletin 155. Oil-storage tanks and reservoirs, with a brief discussion of losses of oil in storage and methods of prevention, by C. P. Bowie. 1917. 73 pp., 21 pls. 25 cents.

Bulletin 158. Cost accounting for oil producers, by Clarence G. Smith. 1917. 123 pp. 15 cents.

Bulletin 163. Methods of shutting off water in oil and gas wells, by F. B. Tough. 1918. 122 pp., 20 pls., 7 figs. 30 cents.

Bulletin 165. Bibliography of petroleum and allied substances in 1916, by E. H. Burroughs. 1919. 159 pp. 20 cents.

Bulletin 177. The decline and ultimate production of oil wells, with notes on the valuation of oil properties, by C. H. Beal. 1919. 215 pp., 4 pls., 80 figs. 30 cents.

Bulletin 180. Bibliography of petroleum and other allied substances, 1917, by E. H. Burroughs. 1920. 170 pp. 25 cents.

Bulletin 182. Casing troubles and fishing methods in oil wells, by Thomas Curtin. 1920. 48 pp., 3 pls., 15 figs. 15 cents.

Bulletin 189. Bibliography of petroleum and other allied substances, 1918, by E. H. Burroughs. 1921. 180 pp. 25 cents.

Bulletin 194. Some principles governing the production of oil wells, by C. H. Beal and J. O. Lewis. 1921. 58 pp., 2 pls., 8 figs. 10 cents.

Bulletin 195. Underground conditions in oil fields, by A. W. Ambrose. 1921. 154 pp., 23 pls., 43 figs. 65 cents.

Bulletin 206. Laws relating to petroleum in all America, by J. W. Thompson. 1921. 645 pp. 40 cents.

Technical Paper 51. Possible causes of the decline of oil wells, and suggested methods of prolonging yield, by L. G. Huntley. 1913. 32 pp., 9 figs. 5 cents.

Technical Paper 53. Proposed regulations for the drilling of oil and gas wells, with comments thereon, by O. P. Hood and A. G. Heggem. 1913. 28 pp., 2 figs. 5 cents.

Technical Paper 70. Methods of oil recovery in California, by Ralph Arnold and V. R. Garfias. 1914. 57 pp., 7 figs. 5 cents.

Technical Paper 130. Underground wastes in oil and gas fields and methods of prevention, by W. F. McMurray and J. O. Lewis. 1916. 28 pp., 1 pl., 8 figs. 5 cents.

INDEX.

A.

Page.

- Air, above oil in tanks, volume 79
  - circulation in tanks, protection against 92
    - protection of tanks from 86
    - *See also* Saturation; Steel tanks; Wood tanks.
  - saturation by gasolines and water, percentages for 89
- Ambrose, A. W., acknowledgment to 4
- Autumn, evaporation losses in 68
  - curves showing 49, 50, 54–57, 59, 61
  - loss in different stages of handling 85
  - *See also* Spring; Summer; Winter.

B.

- Ballard, H. O., acknowledgment to 4
- Bearce, H. W., work cited 23
- Black tanks. *See* Tanks, color of.
- Blends. *See* Gasoline.
- Boiling points, fraction evaporating at, curves showing 94
- Bowie, C. P., acknowledgment to 4
  - work cited 15, 70
- "Breathing," of tanks, definition of 71
- Brown, R. E., acknowledgment to 4
- Burrell, G. A., and Boyd, H. F., work cited 89
- Burrell, G. A., Seibert, F. M., and Oberfell, G. G., work cited 100

C.

- California. Coalinga field. *See* Crudes; Gasolines.
- Capacity. *See* Lease storage-tanks, capacities of.
- Condensation, amount of gas nonrecoverable by 107
- Convection currents, in oil tanks, causes 91
- Crudes, comparison of, methods of 7
  - from different sources, evaporation rate of 103–105
    - curves showing 104, 106
  - gravity of 98
  - gravity loss 92
    - curves showing 93.
    - in dehydrator tests 36
    - in dehydration. *See* Temperature.

Crudes—Continued. Page.

  - loss as. *See* Value lost; Volume lost.
  - rate of evaporation, comparison with gasoline from, curves showing 96, 97
  - source of, relation to evaporation of gasoline from 103

D.

- Dean, E. W., acknowledgment to 4
- Dehydration plant, description of 31
  - figure showing 31
  - tests at, conditions for 30
    - number of 30
  - use of 9
  - *See also* Value lost; Volume lost.
- Dehydrators, views of 32, 34, 35
- Dehydrator tank, diagram of 32
- Dehydrator tests, conditions of 40
  - data of 35
  - description of 33
  - errors in, precautions against 39
  - results of 36
  - temperatures of 34, 36
    - variations in, curves showing 34
- Depth of oil in tanks, measurements of 78
- Distillation, apparatus for 26
  - records of, form for keeping 16
- Distillation tests, correction for 19
  - description of 16
  - errors in 22
  - evaporation loss in 19
    - curves showing 17, 82
  - results, discussion of 74
    - oils from different sources 106
    - oils of different ages, curves showing 75

E.

- Elliot, A. R., acknowledgment to 4
- Empire Gas and Fuel Co., acknowledgment to 4
- Evaporation, definition of 6
  - rates of, *See also* Crudes, gasoline; Latent heat; Lubricating oil; Oil, different ages; Oil field; Temperature; Viscosity.
  - results of 92
  - *See* Fraction evaporating.

Page.
Evaporation losses, causes of 11
  decrease of, means of 86, 87, 91
  determination of 12, 21
    formula for 15, 20
    methods for, comparison of 22
    See also Field methods; Graphic method; Specific gravity formula; Temperature formula.
  effect of 29
  presentation of 27
  probable, estimation of 105
  See also Autumn; Crudes; Dehydrator tests; Distillation tests; Filling tests; Gasoline; Gathering loss; Spring; Summer; Storage tanks; Plant capacity; Transportation loss; Value lost; Volume lost; Winter.

F.

Field methods, determination of evaporation loss by 12, 21
Filling loss, seasonal 85
Filling tests, apparatus for, description of 42
    figure showing 42
  description of 84
  evaporation losses in, curves showing 44
    table showing 85
  number of 30
  results of 43
Flow tanks, seasonal loss in 85
  use of 8
  view of 32
Formulas. *See* Specific gravity formula; Temperature formula.
Foster, D. S., acknowledgment to 4
Fraction evaporating, boiling points of, curves showing 94
  gravity of, curves showing 93

G.

Gas, amount nonrecoverable from oil 107
Gasoline, blends with viscous oil, evaporation of 103
  evaporation rate, comparison with a blend 99, 100
      curves showing 98, 100, 101
    comparison with its crude, curves showing 96, 97
    ratio to that of blends, curves showing 100
    relation to source of crude 103
  from different sources, evaporation rate, discussion of 101
      curves showing 102, 103
  gravity of, relation to evaporation rate of crude 99
      curves showing 100

Gasoline—Continued. Page.
  in crude, evaporation of 103
  loss of. *See* Value lost; Volume lost.
  latent heat of evaporation of 90
  of different gravities, vapor pressure of 89
  saturation of air by, percentages for 89
    curves showing 90
Gathering loss, seasonal 85
Gersdorff, A. L., acknowledgment to 4
Gravity curves, method of plotting 18

H.

Hill, H. H., acknowledgment to 4
Hook gage, description of 24
  use of 32
Housing of tanks, value of 86, 87
  See also Storage tanks; Wood tanks.

J.

Jacketed tanks. *See* Air, circulation; Storage tanks; Steel tanks.

K.

Kansas, oil from, gravity of 81
  Eldorado field. *See* Crudes; Gasolines.

L.

Law, S. M., acknowledgment to 4
Landolt, Hans, and Boernstein, Richard, work cited 90
Lane, E. C., acknowledgment to 4
Latent heat of evaporation. *See* Gasoline; Water.
Lease gathering system, description of 8
Lease storage-tanks. *See* Storage tanks.
Lease-storage tests, number of 30
Lewis, J. O., acknowledgment to 4
Lubricating oil, specific gravity of 99
  blend of. *See* Gasoline.

M.

Magnolia Petroleum Co., acknowledgment to 4
Maryland Refining Co., acknowledgment to 4
Measuring tank, scaffold for, view of 34
  use of 33
  view of 33
Measuring tape, description and use of 24
  expansion of, effect on measurements of 23

Page.

Mid-Continent field, losses in 65, 86
  oil, production in 65, 86
  oil stocks in 86
  storage in, length of 86
  See also Value lost; Volume lost.
Moody, N. K., acknowledgment to 4
Murray, J. P., acknowledgment to 4

N.

Neal, R. O., acknowledgment to 4

O.

Oil, changes from evaporation. *See* Specific gravity, loss of.
  different ages, evaporation rate of, curves showing 72, 73
  for experiments, specific gravity range 51
  for storage tests, specific gravity of 72
  for temperature experiments, gravity range of 51
  thermal expansion in tanks 79
    effect on measurements 23
  See also Temperatures; Volume.
Oil course, well to refinery, description of 8
    figure showing 9
Oil field, age of, relation to rate of evaporation 8
Oil losses, causes of 6
  See also Evaporation losses.
Oklahoma, Garber field, oil from, gravity of 81
    See also Crudes.
  gasoline from, evaporation rate of, curve showing 103
  Mervine field, oil from, gravity of 79
Overshot filling. *See* Filling tests.

P.

Penn, L. A., acknowledgment to 4
Pennsylvania, gasoline from, evaporation rate of, curve showing 103
Perdew, W. E., acknowledgment to 4
Plant capacity, effect on evaporation 41
    diagram showing 41
Pipe-line tanks, use of 10
Prairie Oil and Gas Co., acknowledgment to 4
Production, Mid-Continent field, by months 86

R.

Receiving tanks. *See* Flow tanks.
Red tanks. *See* Tanks, color of.
Refinery tanks, use of 10

Page.

Roofs, of tanks, care of 87, 92
  steel tanks, view of 46, 47
Rittman, W. F., Jacobs, W. A., and Dean, E. W., work cited 102

S.

Sample cans, care and use of 26
Sampler, for tanks, description of 26
Saturation. *See* Air.
Shumate, J. G., acknowledgment to 4
Simmons, J. H., acknowledgment to 4
Sinclair Oil and Gas Co., acknowledgment to 4
Specific gravity, crudes and gasoline 98
  loss of, in distillation 75
    in evaporation, curves showing 93, 94
    in handling 83
  See also Crude; Gasoline; Lubricating oil; Oil; Temperature.
Specific gravity curves, graphic method for 17, 22
Specific gravity formula, comparison with other methods 22
  discussion of 19
Spring, evaporation losses 68
    curves showing 49
    in different stages of handling 85
  See also Autumn; Summer; Winter.
Steel tanks, classification of 53, 63, 71, 72
  expansion of, effect on measurements of 23
  jacketed, description of 46
    diagram of 47
    value of 86, 87
    See also Air, circulation; Housing.
  large, depth measurements of 78
    description of 70
    evaporative conditions in, diagram showing 70
    methods of testing 71
    temperature in. *See* Temperatures, variation.
  losses from 68
  overshot connections for, view of 47
  unprotected, view of 46
  See also Filling tests.
Stocks, Mid-Continent field, by months 86
Storage, average period of 48
  length of, Mid-Continent field 86
Storage tanks, capacities of 45
  different sizes in different seasons, losses from 68
  empty, loss from 62
  evaporation loss, form for recording 14

Storage tanks—Continued. Page.
- jacketed, loss from, curves showing 59–61
  - value of 70
  - views of 48
- housed, loss from, curves showing 58, 61, 62, 65
  - value of 70
- loss in, curves showing 66
  - seasonal 85
- types of, description of 45
  - for temperature tests 51
- unprotected, loss from, curves showing 58–60, 62–64
  - *See also* Steel tanks.
- use of 10
- *See also* Air, circulation; Filling tests; Roofs; Steel tanks; Wood tanks.

Straight, Herbert, acknowledgment to 4

Stuntz, R. M., acknowledgment to 4

Summer, evaporation losses in 68
  - curves showing 49, 50, 54–58, 62, 93, 94
  - in different stages of handling 85
- loss of gravity through evaporation in, curves showing 93, 94
- *See also* Autumn; Spring; Winter.

T.

Tank cars. *See also* Transportation losses.

Tank farms, use of 10

Tanks, color of, discussion of 74
  - effect of, curves showing 74
- *See also* Flow tanks; Lease storage tanks; Measuring tanks; Pipe-line tanks; Refinery tanks; Steel tanks; Storage tanks; Tank farms; Wood tanks.

Temperature, change of, effect on rate of evaporation 49
  - curves showing 50
- effect, in different sized plants 42
  - on gravity lost, curves showing 38
  - on value lost, curves showing 37
  - on volume lost, curves showing 36
- in air space of tanks, importance of 92
- measurement of, accuracy of 76, 77
- method of recording 33
- seasonal, Mid-Continent field 48
  - curves showing 49
- variation in large tanks of 75
  - curves showing 76, 77

Temperature curves. *See* Graphic method.

Page.

Temperature formula, comparison with other methods of 22
- for evaporation loss 20

Temperature tests, method of making 51

Temperature variations. *See* Dehydration tests.

Texas, Ranger, oil from, gravity of 72
- *See also* Crude; Gasoline.

Thermal expansion, effect on measurements 23
- *See also* Oil.

Thieving thermometer, for tanks, description of 24
  - figure showing 25
- temperatures tests with, results of 77

Transportation, lease to refinery, description of 79, 80, 81
  - diagram showing 81
  - losses in 80, 82, 83
    - curves showing 82, 83
    - seasonal 85

V.

Value lost, as crude 42, 68
  - curves showing 63–66
- as gasoline 42
  - curves showing 63–66
- discussion of 27
- estimation of, methods for 28–29
- from different sized tanks 63, 68, 85
  - curves showing 63–66
- in dehydrator tests 36
- in different plants and at different temperatures 42
- in different seasons 68
- in filling tests 85
- in Mid-Continent field 65
- percentage of, discussion of 28
  - from different sized tanks 63, 68
    - curves showing 63, 68
  - in dehydrator tests 36
  - in filling tests 85
  - in Mid-Continent field, curves showing 66
- *See also* Temperature.

Vapor, in tanks, volumetric variation 79

Vapor pressure, definition of 89
- gasolines of different gravities 89

Viscosity, effect on rate of evaporation 91

Volume of oil in tank, errors in measuring 78

Volume lost, discussion of 27
- in dehydrator tests 36
- in different plants and at different temperatures 42
- in different sized tanks in different seasons 68
  - curves showing 54–62
- in filling tests 85
- in Mid-Continent field 65, 86

Volume lost—Continued. Page.
- in storage, method of calculating 45
- oils of different ages, curves showing 72, 73
- percentage of, discussion of 27
  - from different sized tanks in different seasons 68
    - curves showing 54–62
  - in dehydration tests, curves showing 38
    - discussion of 39
  - in different stages of handling 83
  - in filling tests 44, 85
  - in Mid-Continent field 65
    - curves showing 66
  - in transportation, curves showing 83
  - oils of different ages, curves showing 73
  - variations in, causes of 40
- specific gravity of, curves showing 94
- *See also* Temperature.

Page.

Volumetric measurements. *See* Volume lost.

W.

Water, latent heat of evaporation of 90
- saturation of air by, percentages for 80
- vapor pressure of 89

Waltz, C. R., acknowledgment to 4

White tanks. *See* Tanks, color of.

Winter, evaporation losses in 68
- at different stages of handling 85
- curves showing 49, 50, 54–57, 60
- *See also* Autumn; Spring; Summer.

Wood tanks, classification of 53
- purpose of 45
- *See also* Air circulation.
- housing for, figure showing 46
- losses from 68

○